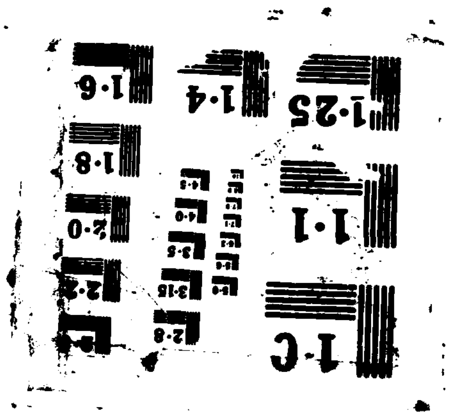
AD-A188 414 ESTIMATING THE SOLAR IRRADIANCE OF AN INTERMOUNTAIN REGION USING GOES (GE (U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH M S WALTERS 1987 1/2

UNCLASSIFIED AFIT/CI/NR-87-112T F/G 4/2 NL


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.8

ESTIMATING THE SOLAR IRRADIANCE OF AN INTERMOUNTAIN

REGION USING GOES SATELLITE DATA:

A TEST OF TWO STATISTICAL MODELS

by

Mark S. Walters

A thesis submitted in partial fulfillment

of the requirements for the degree

of

MASTER OF SCIENCE

in

Soil Science and Biometeorology

Approved:

Major Professor	Committee Member
Committee Member	Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

1987

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFIT/CI/NR-87-~~XXXX~~ 112T	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Estimating The Solar Irradiance Of An Intermountain Region Using Goes Satellite Data: A Test Of Two Statistical Models		5. TYPE OF REPORT & PERIOD COVERED THESIS/DI~~SSERTATIO~~N
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Mark S. Walters		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS AFIT STUDENT AT: Utah State University		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS AFIT/NR WPAFB OH 45433-6583		12. REPORT DATE 1987
		13. NUMBER OF PAGES ~~138~~ 152
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

APPROVED FOR PUBLIC RELEASE: IAW AFR 190-1

Lynn Wolaver 23 Sep 87

LYNN E. WOLAVER
Dean for Research and Professional Development
AFIT/NR

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

ATTACHED

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

ESTIMATING THE SOLAR IRRADIANCE OF AN INTERMOUNTAIN REGION USING GOES SATELLITE DATA: A TEST OF TWO STATISTICAL MODELS

by

Mark S. Walters

A thesis submitted in partial fulfillment

of the requirements for the degree

of

MASTER OF SCIENCE

in

Soil Science and Biometeorology

Approved:

Major Professor

Committee Member

Committee Member

Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

1987

ACKNOWLEDGEMENTS

The data acquisition and analysis was supported by the Utah State Climatologists Office. This research was conducted under supervision of Dr. Gail Bingham of the Department of Soil Science and Biometeorology at Utah State University.

I would like to take this opportunity to thank my supervisor, Dr. Gail Bingham, for his excellent guidance, support and friendship during this project. I would also like to express my sincere appreciation to Dr. Larry H. Hipps and Dr. Ted Alsop of my graduate committee for their guidance and help; Mr. Clifford Raphael for his technical assistance over many personal phone conversations; Mr. Norm Spackman and his computer programming expertise; Mr. John Weaver and Paula Tomlinson, at Colorado State University, who provided and assisted me in collecting the satellite data.

I would like to acknowledge my friends and colleagues in the Meteorology Department at Utah State University, they are Barry, Bill D., Mike, Kelly, Ann, Bill M., Gary, and Dave. Finally, I would like to thank my family for their continued support.

Mark S. Walters

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Estimating the Solar Irradiance of an
Intermountain Region Using GOES Satellite Data

by

Mark Steven Walters

Utah State University, 1987

Major Professor: Dr. Gail Bingham
Department: Soil Science and Biometeorology

The performance of two statistical models that use satellite data to calculate the global solar radiation incident upon the earth's surface are assessed. The estimates are determined for a mid-latitude ten station network and represent a variety of sky cover conditions.

Evaluations of the models for different sky conditions reveal the need for revised regression coefficients for the Hay and Hanson (1978) model and the Tarpley (1979) model. The Hay and Hanson (1978) model was shown to perform better for partly cloudy and overcast sky conditions while the Tarpley (1979) model performed better under clear skies. On an hourly and daily time scale, the Hay and Hanson (1978) model proved to be the better performer.

(152 pages)

CHAPTER I

INTRODUCTION

Surface solar radiation is of considerable significance in fields as diverse as meteorology, forestry, agriculture, and glaciology. In addition to providing for the basic heating and cooling that generates the circulation of the earth's atmosphere and oceans, incoming solar radiation (insolation) is responsible for the production of green plant foods, for providing an alternative energy source, for activating the earth-atmosphere hydrological cycle, and for providing a general environment suitable for human habitation. The amount of insolation can be considered a fundamental measure of the free energy available at the earth-atmosphere boundary.

Current ground-based pyranometer measurements of irradiance are limited to a few weather stations, widely scattered universities and agricultural experiment stations. The quality of data produced from this coarse network relies on good calibration, regular maintenance, and the continuous functioning of all the instruments. These requirements are not always met. In addition, the data from this network can only provide information about large-scale (several hundred kilometers) variability and is of little use for monitoring smaller scale variabilities or remote locations.

Therefore, the current network is generally insufficient to produce accurate insolation estimates for large areas or remote locations of interest.

The only practical sources of data with the required resolution and coverage are meteorological satellites such as the Geostationary Operational Environmental Satellite (GOES). A GOES satellite can cover large areas with adequate ground resolution (1.3 km at 40N) and frequency of observation (11-13 Visual images per day) to be used for the determination of solar irradiance at the earth's surface.

The possibility of using satellite data to estimate solar irradiance at the surface has been demonstrated by Hay and Hanson (1978), Tarpley (1979), Gautier et al. (1980), Brakke and Kanemasu (1981), Gautier (1982, 1983), Gautier and Katsaros (1984), Halpern (1984), Moser and Raschke (1984), Cano et al. (1986), and Justus et al. (1986).

The computer models necessary for estimating incoming solar radiation from satellite data must consider the interaction of radiation with the atmosphere and the underlying surface. This radiative transfer problem involves the absorption, scattering and reflection of radiation energy. These processes determine the transfer of radiation in the earth-atmosphere system and are influenced by the abundance of atmospheric gases and the concentration of aerosols and clouds as a function of height.

1. Objectives

Currently, the irradiance measurements for Utah are obtained at 26 ground stations comprising the Utah Weather Network. The density of surface measurements collected by this network, while not great, is still quite unusual. However, the State Climatologist for Utah has stated the current network fails to accurately quantify the solar resource for over 50% of the state of Utah. The purpose of this study is to determine if a reliable method of estimating solar irradiance using satellite data can be demonstrated for this region.

The specific objectives of this study are: 1) To assess the performance of two published statistical models that use satellite data to estimate the global solar irradiance incident upon the earth's surface; and 2) To consider factors that can be included in these models to improve their use in a mountainous region such as Utah.

CHAPTER II

LITERATURE REVIEW

The first attempts to estimate surface insolation that involved the use of satellite imagery, utilized a variety of satellite systems. The first satellites, used specifically in a study of the earth's radiation budget and for insolation estimates, were a series of polar orbiting meteorological satellites.

The use of polar orbiting satellites, however, presented several limitations to these early insolation studies. This type of satellite can provide only one visible image per day of any given site. The hourly variation in cloudiness, which is the main contributer to the absorption and reflectance of solar energy, could not be addressed. Instead, the early work focused on annual, seasonal or monthly variations over latitudinal or zonal regions.

The question of cloud cover variability from hour to hour can be attempted with geostationary satellite data. This type of data can provide relatively high temporal and spatial resolutions. This makes it ideal for estimating incident solar radiation at the surface.

The first major efforts to estimate incident solar radiation using geostationary satellite data is represented

by the work of Hay and Hanson (1978), Tarpley (1979), Brakke and Kanemasu (1981), Hiser and Senn (1980), and Gautier et al. (1980).

The computer models necessary for estimating incident solar radiation at the surface using satellite data can be divided into two categories: a statistical approach based on fitted relationships between satellite and ground measurements, and a physical approach using radiative transfer models to formulate the relationship between the satellite and ground measurements.

Statistical models are more likely to be precise when applied to small areas, are usually not as general, and require comparison with ground data. The work of Tarpley (1979) is perhaps the best known using this method. The physical approach, on the other hand, requires a simplified model because satellites can only measure a few parameters among the many that affect solar irradiance. The investigations done by Gautier et al. (1980) are probably the best known of the physical methods.

On the few models in use today, most have adopted the statistical approach. For example, Tarpley (1979), utilized a regression technique that related satellite pixel brightness to insolation. This model estimated hourly and daily summer insolation values over the Great Plains of the United States. The standard error of the satellite-derived daily insolation values when compared against pyranometer values was 10% of the mean.

Brakke and Kanemasu (1981) followed a similar approach to predict insolation over Texas (Winter 1976) and the Great Plains (Summer 1977). Their technique produced differing results for the two seasons. The results for the Winter 1976 data set were within 36% of the observed mean, while Summer predictions were within 11% of the Summer observed mean.

Hay and Hanson (1978) used hourly solar irradiance data from four ships, located in the Atlantic Ocean, to develop a statistical relationship between the visible radiance data from the GOES platform and the transmissivity of the atmosphere to solar radiation. Consistent results were found and independent verification showed that six hour irradiance values could be calculated to within 15% of measured data, decreasing to 8% for daily estimates. A revised version of this model was later used to determine hourly and daily solar irradiance values over southwest Canada (Raphael and Hay, 1984) with similar results.

Gautier et al. (1980) developed a simple physical model taking into account the effects of Rayleigh scattering and water vapor absorption, but the main emphasis was on cloud effects. Cloud albedo and absorption were derived from pixel data on the assumption that they are linearly related to the cloud brightness. Comparisons with daily insolation measurements from three pyranometers located in southern Canada showed that the satellite-derived estimates were, on the average, within 9% of the spring and

summer ground measurements for a large variety of cloud conditions. The hourly variations monitored by the satellite also followed very closely the variations measured on the ground.

The above models were developed and tested under a variety of radiation conditions and in differing environments: Tarpley (1979) and Brakke and Kanemasu (1981), the U.S. Great Plains; Hiser and Senn (1980) utilized environmentally different ground data stations over the United States; Hay and Hanson (1978), the Tropical Atlantic; and Gautier et al. (1980), South Central Canada. Few, if any, have attempted to apply their techniques to mountainous terrain where the spatial variation in surface insolation can be extremely large.

The work of Justus et al. (1986), Klink and Dellhopf (1986), Pinker and Cario (1984), Halpern (1984), Cano et al. (1986), Moser and Raschke (1984), and Powell et al. (1984), represent the recent efforts in solar radiation studies, all using geostationary satellite data.

These most recent efforts have progressed using, generally, the same techniques as used in the early studies. A statistical method was used in the majority of the studies. However, the study area and the amount of area covered in each study seems to vary widely. Halpern (1984) developed a physical model whose estimates were compared to surface observed data from Northern California. Justus et al. (1986) used a statistical approach to estimate daily

total insolation on a horizontal surface at 1° spacings in latitude and longitude for the continental United States, Mexico and parts of South America. Cano et al. (1986) presented a statistical method for the determination of the global solar radiation of Europe using geostationary METEOSAT images. Moser and Raschke (1984) computed daily sums of the downward solar radiation from METEOSAT I and II imagery over Europe and North Africa.

CHAPTER III

DATA ANALYSIS

1. Strategy

The strategy developed for this study involved collecting a surface based ground truth data set and a GOES satellite data set, for the months of June and August, 1986. The surface data set was obtained at Utah State University while the satellite data set was obtained from the Atmospheric Science Center at Colorado State University. Once the data sets were obtained, two published statistical models were tested by comparing the calculated irradiance values to the ground truth surface data. As a result of this comparison, revised regression coefficients were developed using three days of data from four of the study sites. The days used to develop the regression coefficients were selected to represent clear and partly cloudy sky conditions. The revised models were again tested over the network of sites.

2. Data sets and data processing

The summer time period selected for this study was based mainly on the availability of the meteorological and satellite data sets. The meteorological data set presented the least amount of concern since reliable data

has been collected and archived here at Utah State University since 1981. By far, the most limiting factor presented during the data collection phase of this study was the availability and cost of the satellite data.

Satellite data are archived on a limited basis at the Atmospheric Science Center at Colorado State University. A study called Project FIRE is currently under way and is designed to better understand the characteristics of cirrus and stratocumulus cloud systems. Project FIRE involves collecting GOES satellite data on a 6 day on - 9 day off schedule for a four-year period that began in January, 1986. Data collection was intensified during the months of June through August, 1986 such that hourly images ranging from sunrise to sunset were available. This study utilizes the June and August 1986, data set.

The data set met the basic conditions necessary to complete this study. The primary requirement called for at least five usable satellite images per day so that an accurate estimate of daily solar irradiance could be accomplished (Justus et al., 1986). The second condition called for a spatial resolution better than 8 km. Additionally, the data set offered at least 18 days of hourly satellite imagery, under differing sky conditions, for analyses. Lastly, this data set provided one very important advantage, it was available on a data exchange basis.

3. Surface irradiance data set

The radiation data set for this study were collected from 10 stations of a 26 station network comprising the Utah Weather Network. The area spans a 550 km by 160 km (88,000 sq. km) section of Utah paralleling the Wasatch and Uinta mountain ranges. The locations of the ten stations of interest are shown in Figure 1 and listed on Table 1. The network was established in 1981 by Dr. Inge Dirmhirn and Dr. Leanard Hall, and is designed to provide quality solar data (Bingham et al., 1984). Among the quantities measured at each site are global solar irradiance, air temperature, relative humidity, wind speed, wind direction, maximum wind gust, precipitation, rain gauge temperature, and soil temperature. For this study only the temperature, relative humidity, and solar radiation data are of interest.

At each measurement site, the solar irradiance is measured by a Licor LI-200SCZ silicon pyranometer. The spectral response of the silicon photodiode extends over a spectral region of 0.4 - 1.1 um. Temperature values are measured with a Campbell Scientific 101 temperature probe and relative humidity is measured with a Campbell Scientific 201 relative humidity sensor. The instruments are sampled every minute and recorded on a Campbell Scientific CR21 data logger and are summed to provide hourly totals. The general accuracy of the instrumentation is well within

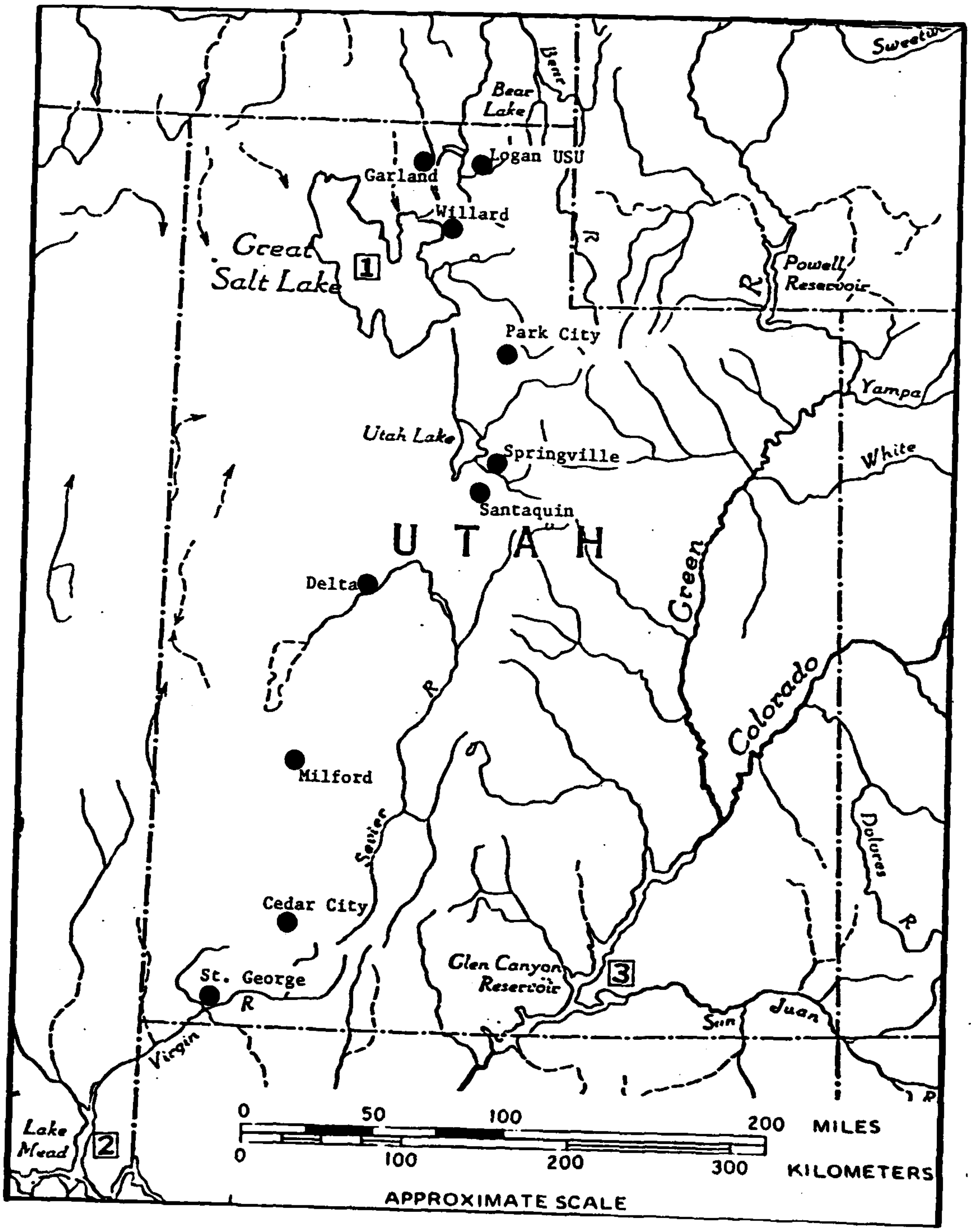


Fig. 1. Location of the Utah Weather Network Stations used in the study as well as the primary landmarks used to navigate the satellite imagery.

Table 1. Location of Utah Weather Network Stations used in the study.

Location	Latitude (N)	Longitude (W)	Elevation (ft)
Cedar City*	37 45'.00"	113 01'.50"	5807
Delta	39 25'.45"	112 37'.30"	4659
Garland*	41 44'.00"	112 10'.30"	4400
Milford*	38 22'.42"	112 59'.00"	5000
Springville*	40 07'.40"	111 42'.30"	4800
St. George	37 04'.00"	113 30'.55"	2887
Santaquin	39 59'.55"	111 46'.25"	4800
Willard	41 26'.44"	112 02'.00"	4350
Park City	40 39'.00"	111 30'.00"	6800
Logan	41 45'.20"	111 47'.30"	4888

* Used to develop revised regression coefficients.

their published specifications. The data for the 10 stations of this study are collected nightly, via telephone lines, quality checked and archived on a floppy disk.

Factors that contribute to the amount of insolation received at the surface are season of the year, latitude, elevation, time of day, air quality (turbidity, etc.), and cloudiness. Since cloud cover controls, to a large extent, the amount of solar radiation reaching the ground, days

from each month were selected representing clear, partly cloudy and overcast cloud cover conditions. Initially, a data set of 27 summer days was selected for analysis. This, later, had to be cut to 18 days (see Table 2) because of navigational problems due to the movement of the satellite.

4. Satellite data set

The satellite data set used in this study were from a Geostationary Operational Environmental Satellite (GOES) operated by the National Oceanic and Atmospheric Administration (NOAA). The GOES satellite was maintained at Earth synchronous altitude, 35800 km (21480 miles) above the Earth's equatorial plane. At this altitude its west to east motion equals that of the Earth beneath, ideally remaining stationary at a desired longitude (Clark, 1983).

The environmental sensor onboard the satellite is a Visible and Infrared Spin Scan Radiometer (VISSR). The sensor measures radiance reflected from the Earth in the visible (0.55 - 0.75 um) and infrared (10.5 - 12.6 um) regions of the electromagnetic spectrum at a ground resolution of 1 km (visible data) at the equator. For this study only the visible data were used.

The visible data are in the form of 8-bit count values ranging from 0-255 counts. The minimum value is the signal

Table 2. The days and sky conditions used in this study.

Day/Month	Julian Day	Sky Condition
5 June	156	partly cloudy
6 June	157	clear
7 June	158	clear
8 June	159	partly cloudy
9 June	160	partly cloudy
21 June	172*	clear
22 June	173	clear
23 June	174*	partly cloudy
24 June	175	partly cloudy
25 June	176	partly cloudy
5 August	217	partly cloudy
6 August	218	clear
8 August	220	partly cloudy
9 August	221	clear
10 August	222	clear
20 August	232	partly cloudy
21 August	233*	partly cloudy
24 August	236	partly cloudy

* Used to develop revised regression coefficients.

received from a black surface, and the maximum value is the signal received from a surface of 100% reflectance. The

surface is also assumed to reflect radiation incident on it equally in all directions. This type of surface is called a Lambertian surface.

The satellite data used in this study are archived at the Atmospheric Science Center of the University of Colorado. The data are stored in digital form on magnetic tapes and can be used both as image and digital data. Filtered satellite data corresponding to the days listed in Table 2 were obtained by first specifying the number of pixel lines and elements in the image (in this case 512 by 512), and by specifying the latitude and longitude coordinates of the image center. All of the images were centered on 40N, 110W and contain all the stations in the Utah Weather Network plus areas of Nevada, Colorado, Arizona, and Wyoming.

5. Problem areas

To properly test the models used in this study the meteorological and satellite data sets described in previous sections must be combined. These data sets are vastly different leading to a number of problems.

a. Completeness of data sets

As mentioned in previous sections, the Project FIRE satellite data were collected on a 6 day on - 9 day off schedule. This schedule allows the collection of only

twelve days of imagery, from each month, for analyses. Additionally, two images for each day were not collected during Project FIRE. They are for the hours of 7 AM and 6 PM local time (DST). For a data perfect condition, twelve satellite images were available from 6 AM to 9 PM local time (DST). For the month of August, only ten visible images were available due to the later sunrise and an earlier sunset.

The surface data for the ten sites in this study are automatically collected via telephone lines. This collection system was installed during the summer of 1986. Seven of the sites were on line by June and three came on line during July (Logan, Park City, and Santaquin). June data for these three sites were not available. Additionally, equipment failures caused missing data at scattered sites and times.

As a result of missing data from the satellite and the surface irradiance data sets, most of the 18 days evaluated in this study have some missing data.

b. Spectral ranges and sensor viewing angles

The satellite measurements were instantaneous measurements, made once an hour, over a small solid viewing angle. The pyranometer measurements were collected from all angles of a hemisphere and were integrated over an hour. An assumption is made that an instantaneous satellite measurement taken on the hour can be made to approximate a

pyranometer measurement averaged over an hour. Additionally, the pyranometer measurements extend over a spectral region of 0.4 - 1.1 um while the satellite data extend over the smaller visible band (0.55 - 0.75 um). An attempt is made to partly account for the angle and time discrepancies by spatially averaging the satellite radiation estimates over a 5 x 5 pixel box. Averaging over the 5 x 5 array also attempts to account for the variations in the eight visible sensors on the VISSR (Gautier, 1982). The 5 x 5 pixel array size was based on a navigational accuracy of one to two pixels.

c. Navigation

The accuracy of the results obtained in this study are directly related to the ability to align points on a satellite image to the same points on the Earth's surface. This is accomplished by means of a procedure called "navigation."

To assure accurate alignment of the imagery, navigation was accomplished in two separate procedures. Initial navigation of the satellite imagery was performed using a model described by Hambrick and Philips (1980). The model is based on the knowledge of some physical parameters of the satellite such as orbit, altitude, etc., and both stellar and terrestrial navigation points. The relative accuracy of this procedure is claimed to be one pixel. However, visual comparison of the imagery on the COMTAL image processor often revealed much larger errors.

To accurately navigate the satellite imagery, a final procedure called "roaming" was accomplished. This procedure relies totally on visual identification of landmarks on the Earth's surface and depends on relatively clear skies. An accuracy of one or two pixels was achieved by selecting a particularly clear and sharp image as a "base image," then visually inspecting each satellite image on the COMTAL image processor and aligning the positions of known landmarks to those of the base image. When sequential images were compared, a consistency of position of a given feature was achieved. Examples of landmarks used to navigate the images extend over Utah, Nevada, and Colorado and include the Great Salt Lake, Lake Mead, Lake Powell, Bear Lake, the Great Salt Lake Desert, and the Wasatch and San Juan Mountain Ranges (see Figure 1). In clear sky conditions the primary navigational features were the Great Salt Lake, Lake Mead, and Lake Powell. In nearly every image at least two of the primary navigational features were visible. It was necessary in only a few of the overcast situations to use secondary navigational features such as mountain ranges and smaller lakes.

An additional and separate navigational problem was discovered during the satellite data collection phase. The current GOES network consists of only one operational GOES satellite, instead of two. The GOES-East (GOES-5) VISSR ceased to operate in the Spring of 1985. As a result,

the only operational satellite (GOES-6) was moved during the hurricane season of 1986 to better cover the western Atlantic. It took approximately 40 days to move the satellite from its primary location at 108W to its summer location at 98W. The satellite was moving from 18 June to 28 July and created several unforeseen problems as related to this study.

The first problem concerns the accuracy of the navigation during the time the satellite was in motion; from June 18 to 28 July. To save fuel, the satellite is moved slowly so the change in the viewing angle of the satellite was negligible for the first few days. For this reason, the images through June 24 proved to be acceptable. The data for July, however, proved to be unusable due to errors in navigating the images as the satellite was relocated.

Once the satellite was at its summer location of 98W, it became necessary to roam the August satellite images to a base image selected from the August imagery. Clearly, once the satellite had been relocated, the location of every navigational feature would change as well as the station pixel coordinates (see Table 3).

It was decided to treat the June and August data as separate data sets and account for the location of the satellite within the two models. Namely, the location of the satellite for the June data would be 108W and the location of the satellite for the August data would be 98W.

Table 3. The latitude, longitude and pixel coordinates for each measurement site during June and August.

	Latitude (N)	Longitude (W)	Pixel Coordinates June X	June Y	August X	August Y
Cedar City	37.75	113.025	171	365	174	341
Delta	39.42	112.62	191	234	195	218
Garland	41.73	112.17	213	52	218	49
Milford	38.37	112.88	173	317	177	296
Springville	40.12	111.705	236	179	241	167
St. George	37.07	113.51	147	419	150	391
Santaquin	39.99	111.77	233	189	237	177
Willard	41.44	112.03	220	75	224	70
Park City	40.65	111.50	246	137	250	128
Logan	41.75	111.78	232	50	236	47

The relocation of the satellite resulted in having to develop separate models for both months, selecting a separate base image for both months, specifying the separate station pixel locations for each month and, of course, the deletion of all the July data.

6. Precipitable water

Moisture is one of the meteorological parameters that affects the amount of solar radiation reaching the surface. The Tarpley (1979) model accounts for this variable by including precipitable water within its framework. Tarpley used radiosonde based precipitable water data from the National Meteorological Center (NMC) data file. The files were updated twice daily; the 0000 GMT file contained information most nearly time-coincident with the satellite data. Additionally, precipitable water values for each target were retrieved from the nearest NMC grid point which could be as far as 2 degrees latitude and longitude from the target (Tarpley, 1979). Obviously, this technique could be open to much error.

An alternative technique was used in this study. Using Smith's (1966) empirical formulation, given a surface dewpoint temperature, precipitable water values can be calculated for each of the measurement stations, based on a model atmosphere. The use of Smith's emperical technique offers the ability to update the precipitable water data on an hourly basis for all of the study sites. The published equation is:

$$\ln (u) = [0.1133 - \ln(\lambda + 1)] + 0.0393\ Td \quad \text{(Smith, 1966)}$$

u = precipitable water in cm

Td = surface dewpoint temperature (F)

λ = latitude and seasonally adjusted coefficient

Atwater and Ball (1976) computed solar radiation for eleven stations in the U.S. They showed that the method of determining precipitable water, from radiosonde observations or estimating it from the surface dewpoint temperature, had little effect on the calculated solar radiation. Raphael (1983) tested this finding by calculating solar radiation using Smith's formulation and found precipitable water values determined from the surface dewpoint temperature produced solar radiation estimates closer to the observed solar radiation, and that precipitable water values derived from the radiosonde data were largely inappropriate due to the errors introduced.

7. The models

The models chosen for evaluation are those of Hay and Hanson (1978) and Tarpley (1979). The two models were originally developed for different environments and tested under a variety of radiation conditions, but neither has been tested for use over a mountainous region such as Utah. For this reason, both models were initially tested using the original model parameters and regression coefficients over select days of the study period.

The model developed by Hay and Hanson (1978) is the simplest of the two models. The basic equation, where the irradiance at the surface I_s, is written as:

$I_s = I_o \cos\theta(a-bSR)$ (Raphael, 1983)

I_o = solar constant (1353 W/m)

SR = normalized satellite reflectance

a,b= regression coefficients

θ = local solar zenith angle

The Hay and Hanson (1978) model utilizes a satellite calibration technique that converts the satellite pixel brightness counts into a reflectance value. The calibration procedure used in the model was provided by E. Smith, Colorado State University (Raphael, 1983). Using this procedure a computer-based "look-up table" is generated relating the brightness counts to relevant normalized reflectance and irradiance values. The normalized reflectance for any pixel brightness value is obtained simply by locating this brightness value in the look-up table and retrieving the appropriate normalized reflectance (Raphael and Hay, 1984).

The value retrieved from the look-up table is used in the final form of the irradiance calculation. The final form of the irradiance calculation is written as:

I = a(xext) + b(xext)xir

a,b = regression coefficients

xext = the extraterrestrial global irradiance that is calculated from the product of the solar constant and the cosine of the zenith angle at the satellite image time.

xir = the product of the quantity retrieved from the look-up table, the normalized reflectance value, and the inverse of the cosine of the solar zenith angle.

The only supplementary data, the surface measured irradiance value, is used by the model in a statistical comparison to the calculated irradiance value.

The model presented by Tarpley (1979), was developed and tested using data from the United States Great Plains. An important feature of the model is the brightness parameterization given by:

$$B = a + b\cos\theta + c\sin\theta\ \cos\phi + d\sin\theta\ \cos^2\phi \quad \text{(Tarpley, 1979)}$$

B = predicted minimum brightness

ϕ = azimuth angle between sun and satellite

θ = local solar zenith angle

a,b,c,d = regression coefficients

This equation accounts for the changing incident flux, the changes in the target brightness due to shadowing at the surface and anistropic scattering.

Cloud coverage is determined from a two-threshold method as presented by Shenk and Salomonson (1972). Three categories are determined by this method. They are clear, partly cloudy (50% cloud cover) and cloudy (100% cloud cover). The cloud factor (n) is computed using the equation:

$$n = \frac{.5N_2 + N_3}{N_1 + N_2 + N_3} = \frac{N_2 + 2N_3}{2N} \qquad \text{(Tarpley, 1979)}$$

n = cloud factor

N = total number of pixels in target area

N_1, N_2, N_3 = number of pixels in clear, partly cloudy, and cloudy categories respectively

The clear/partly cloudy threshold (T1) is the predicted clear brightness plus twelve counts. Any pixel value greater than or equal to T1 is considered clear. The partly cloudy/cloudy threshold (T2) is the predicted clear brightness plus twenty counts. Any pixel value greater than T1 but less than T2 is considered to be partly cloudy. Pixels greater than T2 are considered cloudy.

Three regression equations were developed to estimate the irradiance at the surface under clear, partly cloudy and overcast sky conditions. For clear sky conditions, when the cloud factor (n) is less than .4, the hourly surface irradiance (I_s) is calculated using

$$I_s = a_1 + b_1 \cos\theta + c_1 \psi + d_1 n + e_1 \, (Im/B)^2 \qquad \text{(Tarpley, 1979)}$$

When a partly cloudy condition occurs, the cloud factor (n) is between .4 and 1.0, the hourly surface irradiance I_s is calculated using

$$I_s = a_2 + b_2 \cos\theta + c_2 n \, (Icld/B_o)^2 \qquad \text{(Tarpley, 1979)}$$

When the cloud factor (n) equals 1.0 an overcast sky

condition exists and I is computed using the equation

$$I_s = a_3 + b_3 \cos\theta + c_3\ (Icld/B_o)^2 \qquad \text{(Tarpley, 1979)}$$

where I is the hourly surface irradiance, I_m is the mean target brightness, B is the predicted clear brightness, Icld is the mean cloud brightness, B_o is the normalized clear brightness, the regression coefficients are a,b,c,d,e (the original values are used here) and (ψ) is the atmospheric transmittance.

Atmospheric transmittance (ψ) is calculated using the following equation

$$\psi = \psi_{ws} \cdot \psi_{wa} \cdot \psi_r \qquad \text{(Tarpley, 1979)}$$

ψ_{ws} = 1-0.00225um transmission due to water vapor scattering

$\psi_{wa} = 1-0.077(wm)^{.3}$ transmission due to water vapor absorption

$\psi_r = 0.972-0.0826m + 0.00933m^2$ transmission due to Rayleigh scattering

u = precipitable water (cm)

z = station elevation (m)

m = optical air mass = $e^{-(z/8243)}/[\cos\theta + .15/(93.885-\theta)^{1.253}]$

8. <u>Satellite azimuth angles</u>

To determine the satellite azimuth angles (a), necessary in both model calculations, several equations from Sellers (1965) are used. The satellite azimuth angle from south is

calculated by first determining the sun's azimuth (Z). Using spherical trigonometry it follows:

$$\cos Z = \sin\phi \sin\delta + \cos\phi \cos\delta \cos h \qquad \text{(Sellers, 1965)}$$

ϕ = station latitude

δ = angular distance of the satellite north or south of the equator. For a geostationary satellite $\delta = 0$.

h = hour angle. The longitude of the station minus the longitude of the satellite.

The satellite azimuth angle can then be calculated using:

$$\sin a = \frac{\cos\delta \sin h}{\sin Z} \qquad \text{(Sellers, 1965)}$$

As mentioned earlier, the movement of the satellite from 98W to 108W during the study period required the development of two sets of satellite azimuth angles.

CHAPTER IV

RESULTS AND DISCUSSION

1. The Hay and Hanson model

The initial test of the Hay and Hanson (1978) model was performed for all of the study sites using all the available days from the data set. Prior to the test, Julian days 172, representing clear sky conditions and days 174 and 233 were selected for analysis representing partly cloudy sky cover conditions.

The averaged hourly calculations from the initial test indicate that the model is unbiased towards any of the test sites. The results also indicate that the model is generally consistent for two sky cover situations. The model underestimates clear conditions that remain clear all day (day 172) and overestimates partly cloudy situations that remain partly cloudy all day (day 233). The models performance seems to decrease for those conditions that start the day clear and end the day with cloudy skies. The values listed in Table 4 and Figures 2-12 indicate the performance of the model at select locations of the study area (see Appendix for complete statistics on the individual stations).

Table 4. Hourly statistics, at select sites, from the initial test of the Hay and Hanson model (1978) using the original regression coefficients. The three days represent clear (day 172), and partly cloudy (days 174, 233) sky conditions.

	IRRADIANCE					
DAY	OBS	CALC	N	MBE%	RMSE%	LOCATION
172	26049.0	25413.6	11	2.5	8.3	Cedar City
172	25942.9	25921.9	11	.1	.3	St. George
172	26494.1	26359.5	11	.5	1.7	Garland
172	26305.7	26283.6	11	.1	.3	Springville
174	20562.5	22513.0	11	-8.7	28.7	Cedar City
174	23403.2	22600.1	11	3.6	11.8	Milford
174	23564.4	23446.3	11	.5	1.7	Delta
233	12459.4	14411.3	9	-13.5	40.6	Milford
233	15059.9	19179.8	9	-21.5	64.4	Park City
233	14469.1	17458.3	9	-17.1	51.4	Logan
233	19094.4	19868.6	9	-3.9	11.7	Garland
TOT:	233404.6	243456.0	113	-4.1		

The figures depicting day 172, the clear day, indicate that the model tends to underestimate the irradiance during mid day and overestimate during the morning and evening hours. The values in Table 4 indicate that these high and

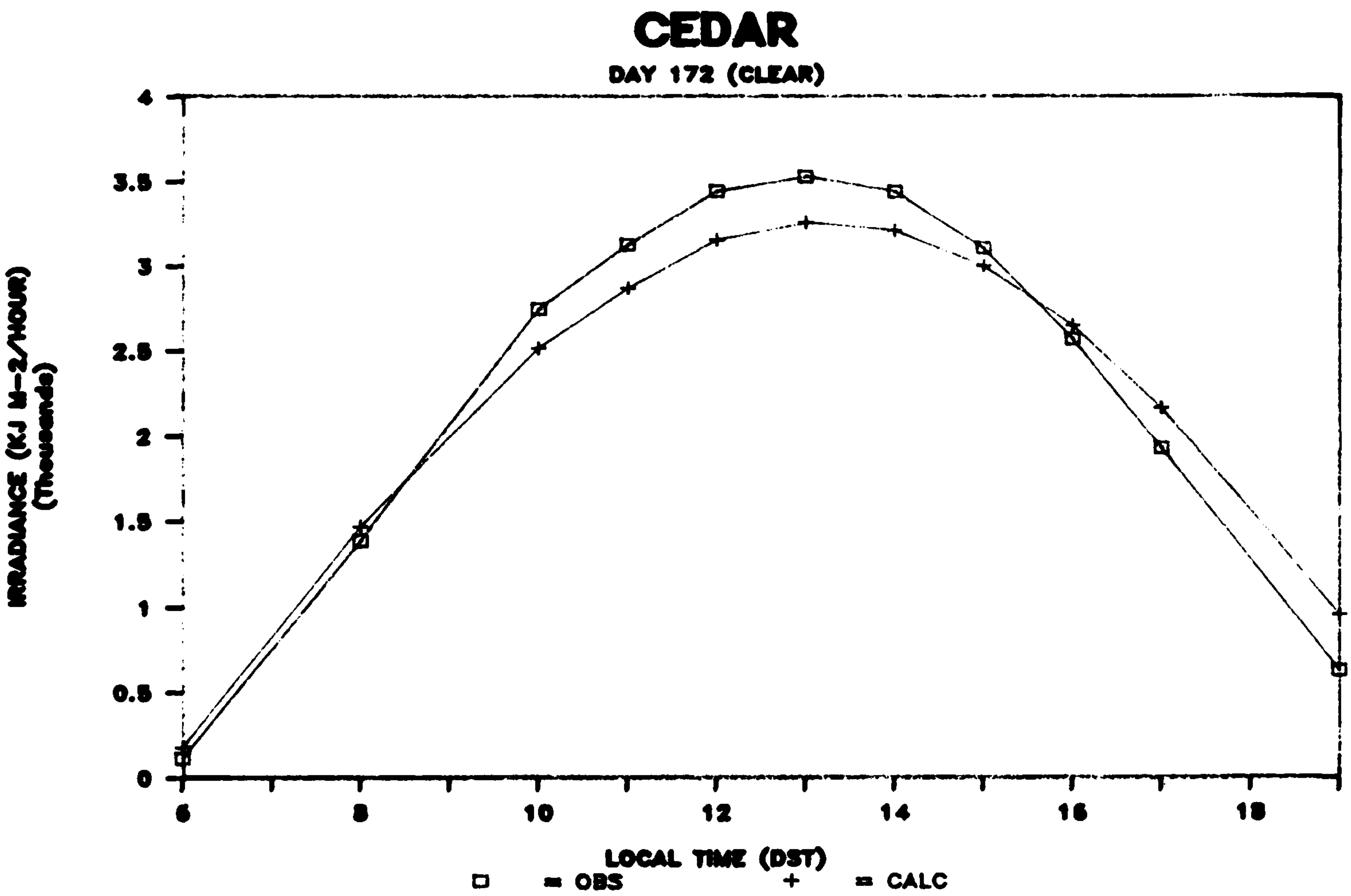


Fig. 2. Calculated and observed irradiance using the original regression coefficients from the Hay and Hanson (1978) model.

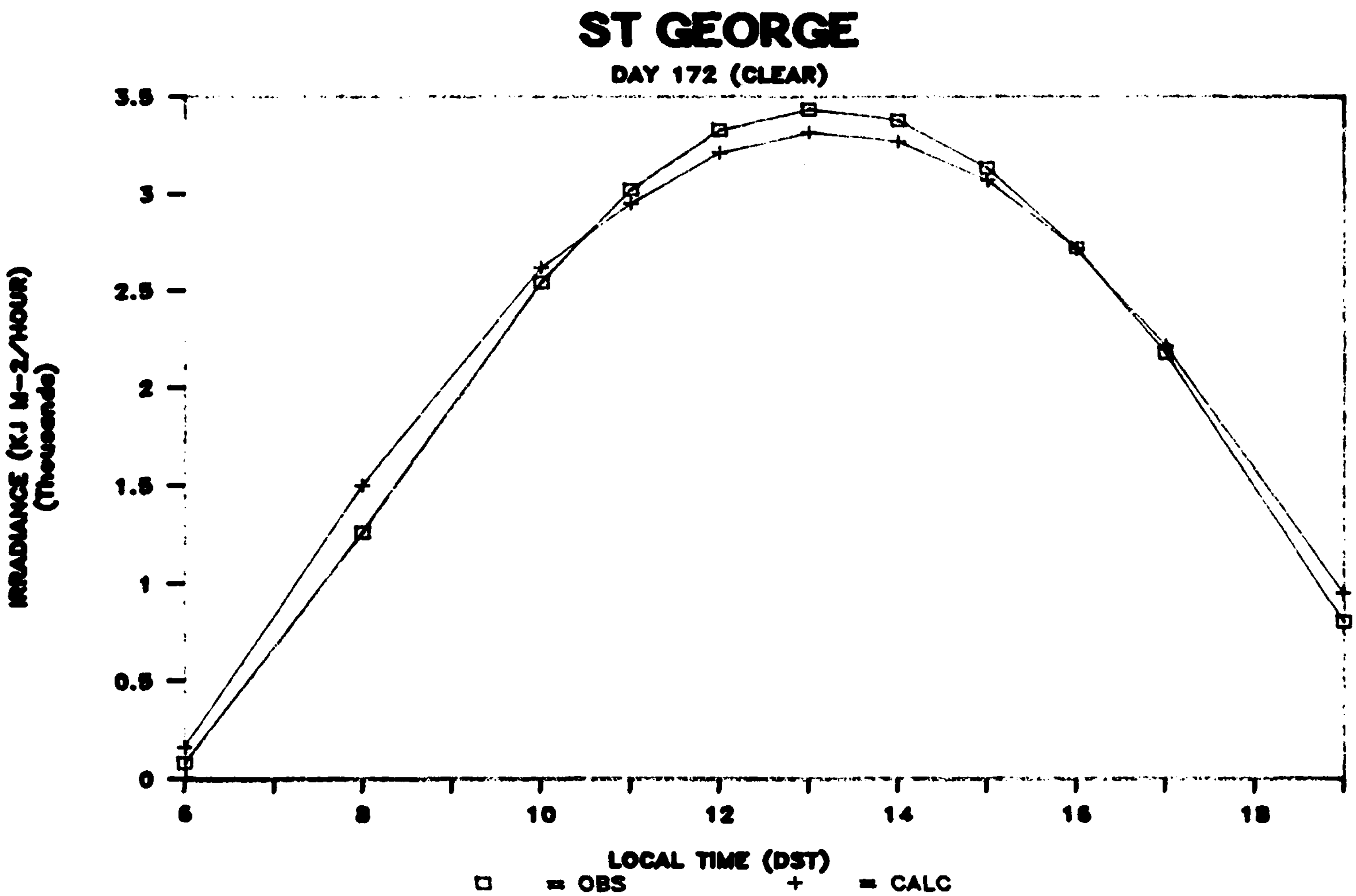


Fig. 3. Calculated and observed irradiance using the original regression coefficients from the Hay and Hanson (1978) model.

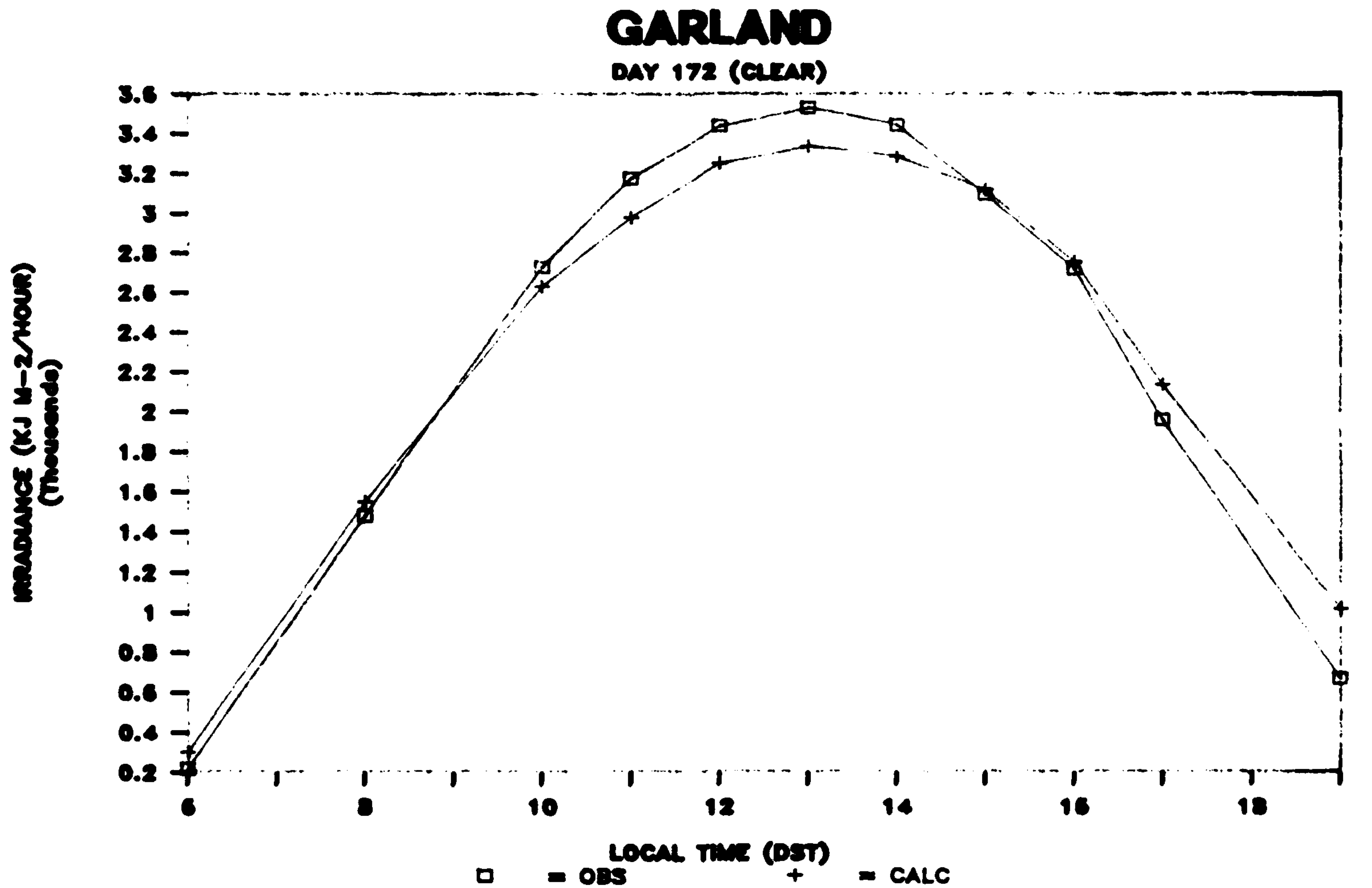


Fig. 4. Calculated and observed irradiance using the original regression coefficients from the Hay and Hanson (1978) mcdel.

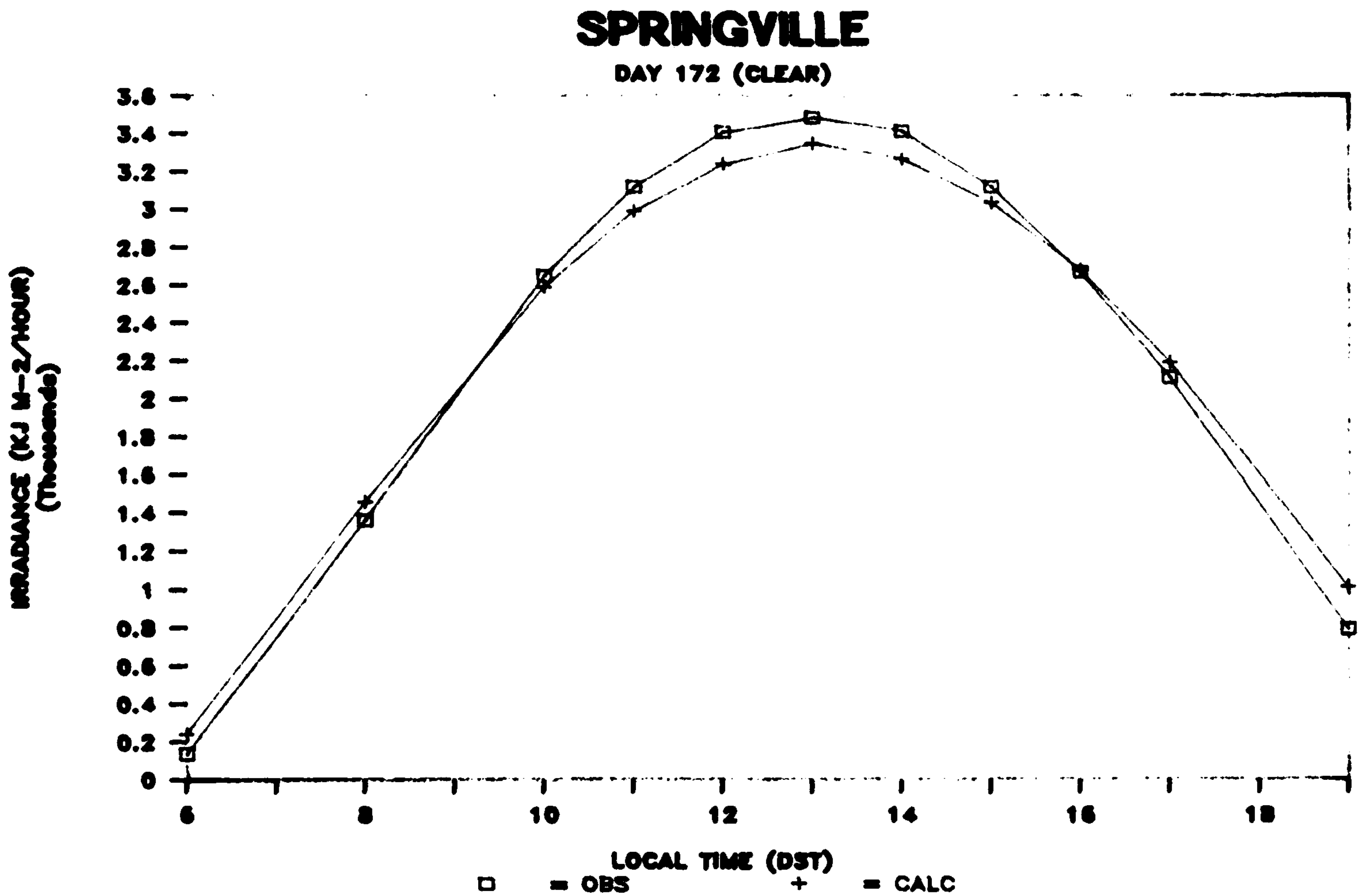


Fig. 5. Calculated and observed irradiance using the original regression coefficients from the Hay and Hanson (1978) model.

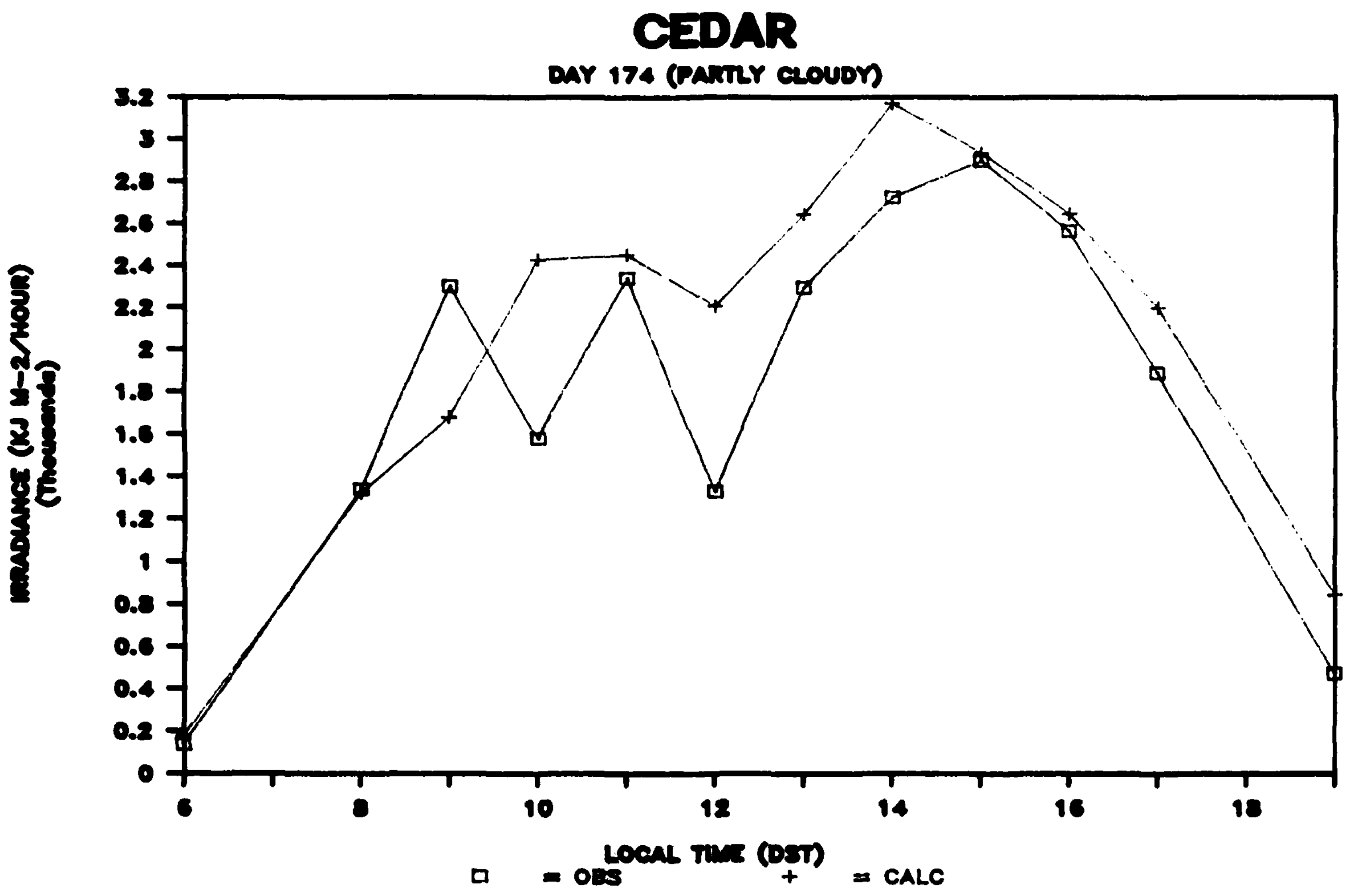


Fig. 6. Calculated and observed irradiance using the original regression coefficients from the Hay and Hanson (1978) model.

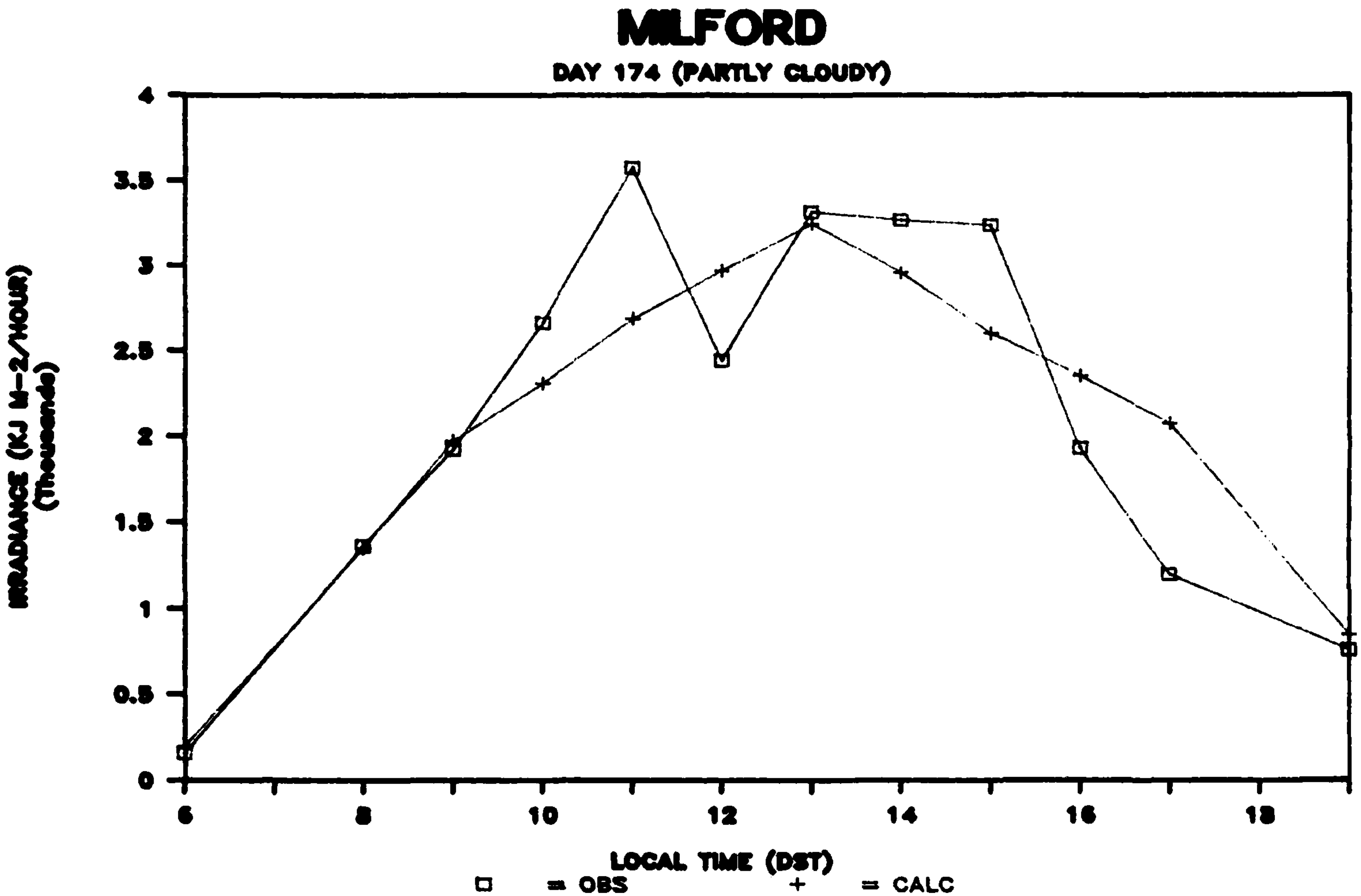


Fig. 7. Calculated and observed irradiance using the original regression coefficients from the Hay and Hanson (1978) model.

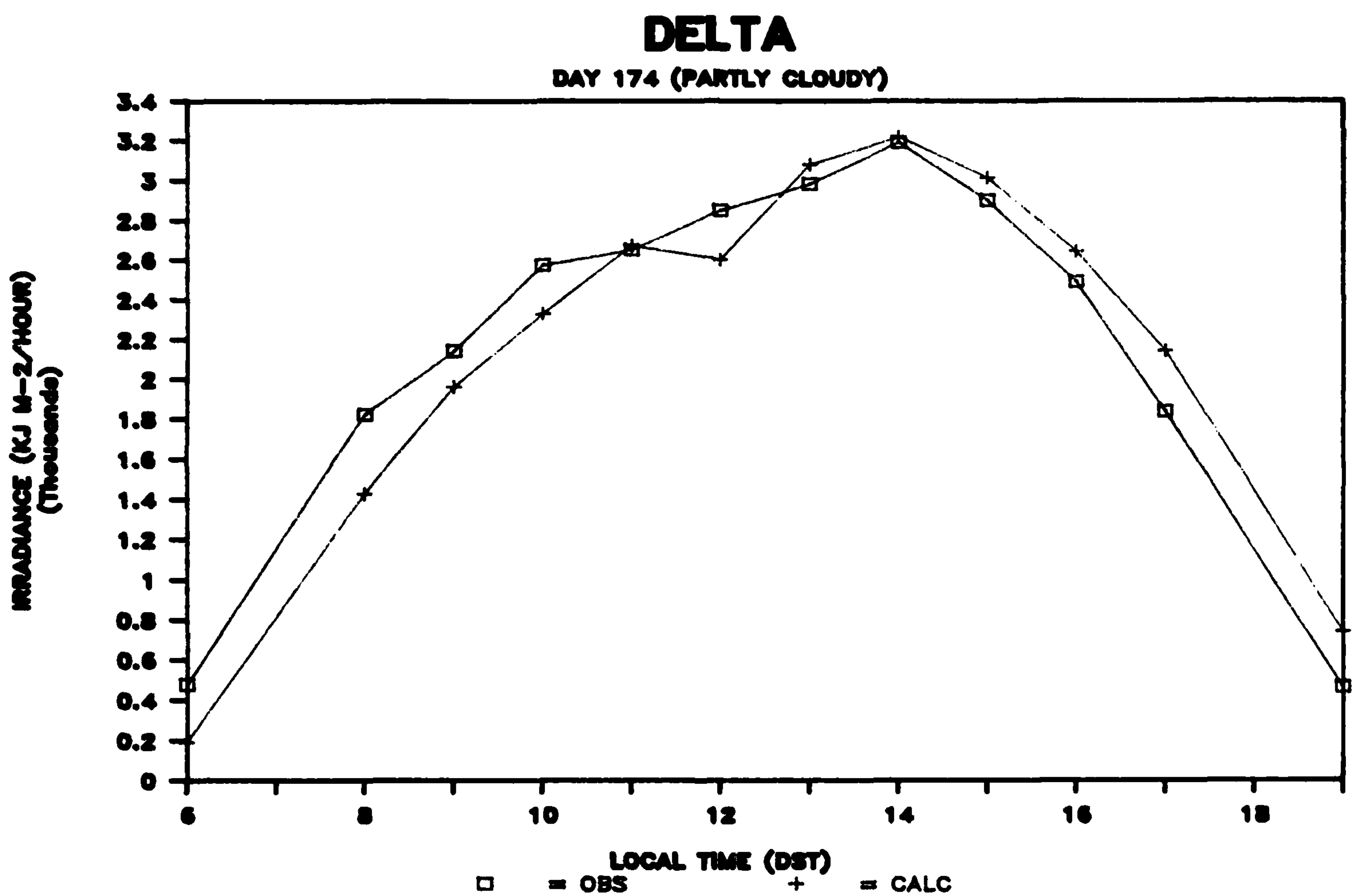


Fig. 8. Calculated and observed irradiance using the original regression coefficients from the Hay and Hanson (1978) model.

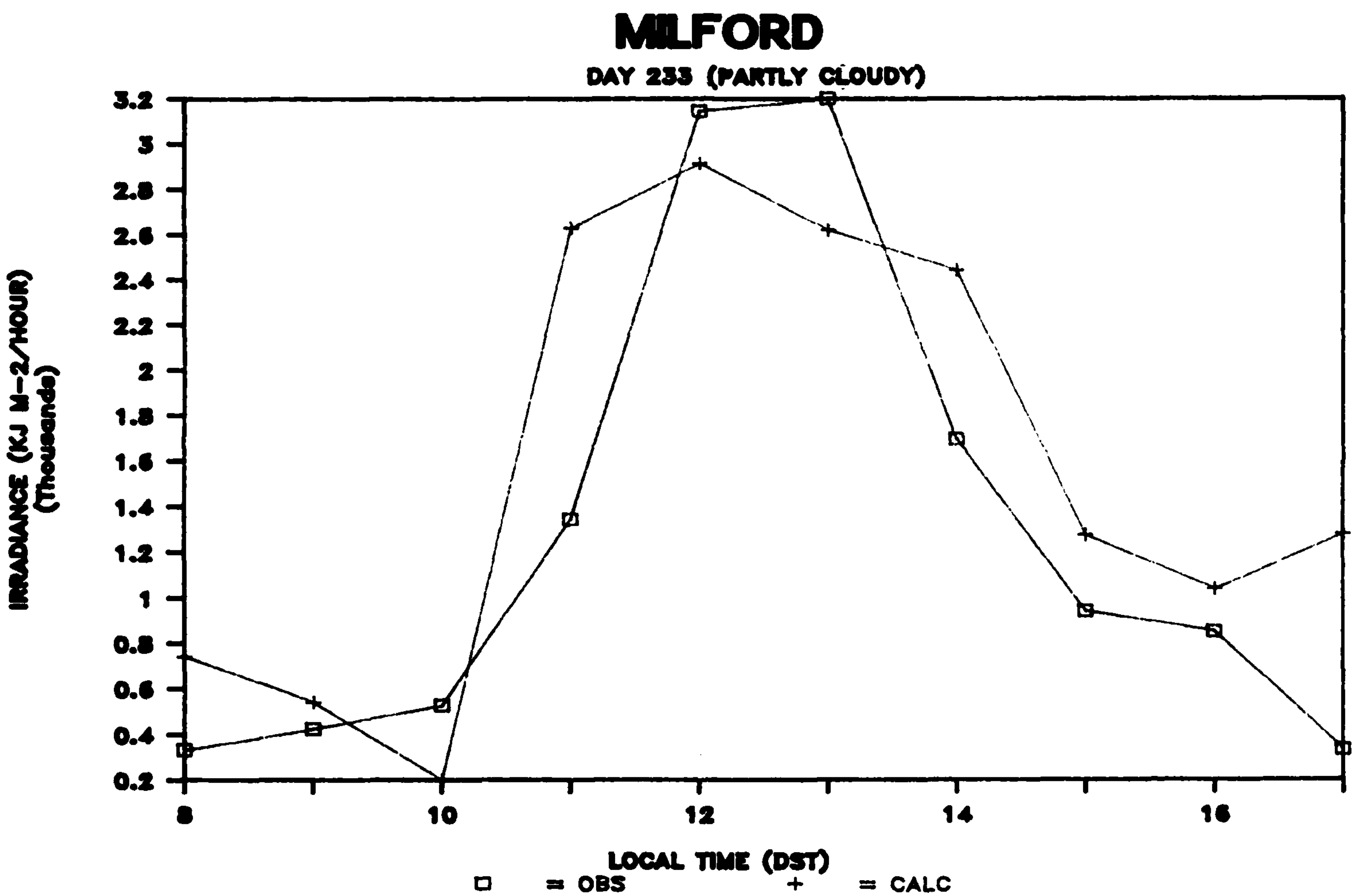


Fig. 9. Calculated and observed irradiance using the original regression coefficients from the Hay and Hanson (1978) model.

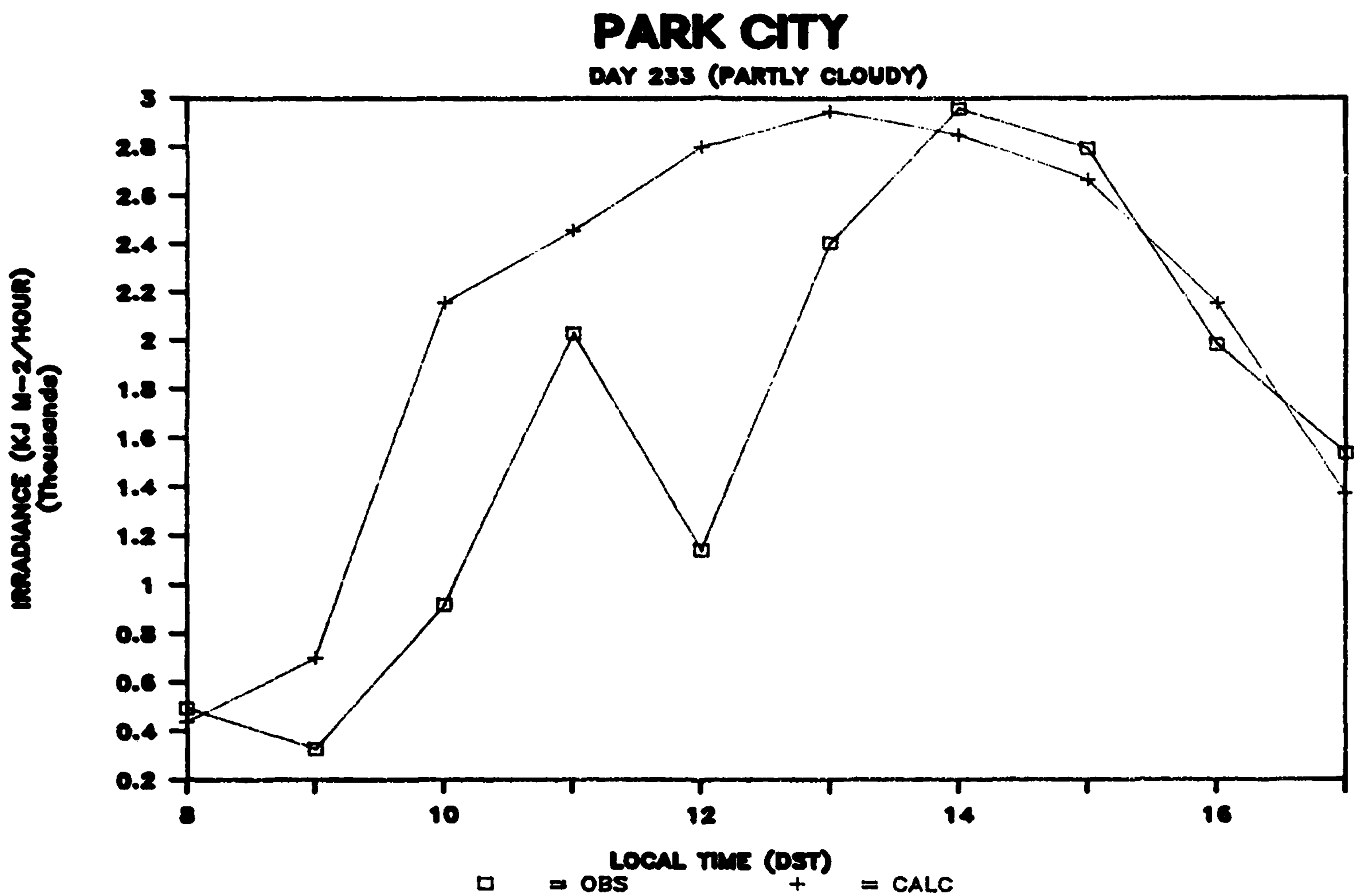


Fig. 10. Calculated and observed irradiance using the original regression coefficients from the Hay and Hanson (1978) model.

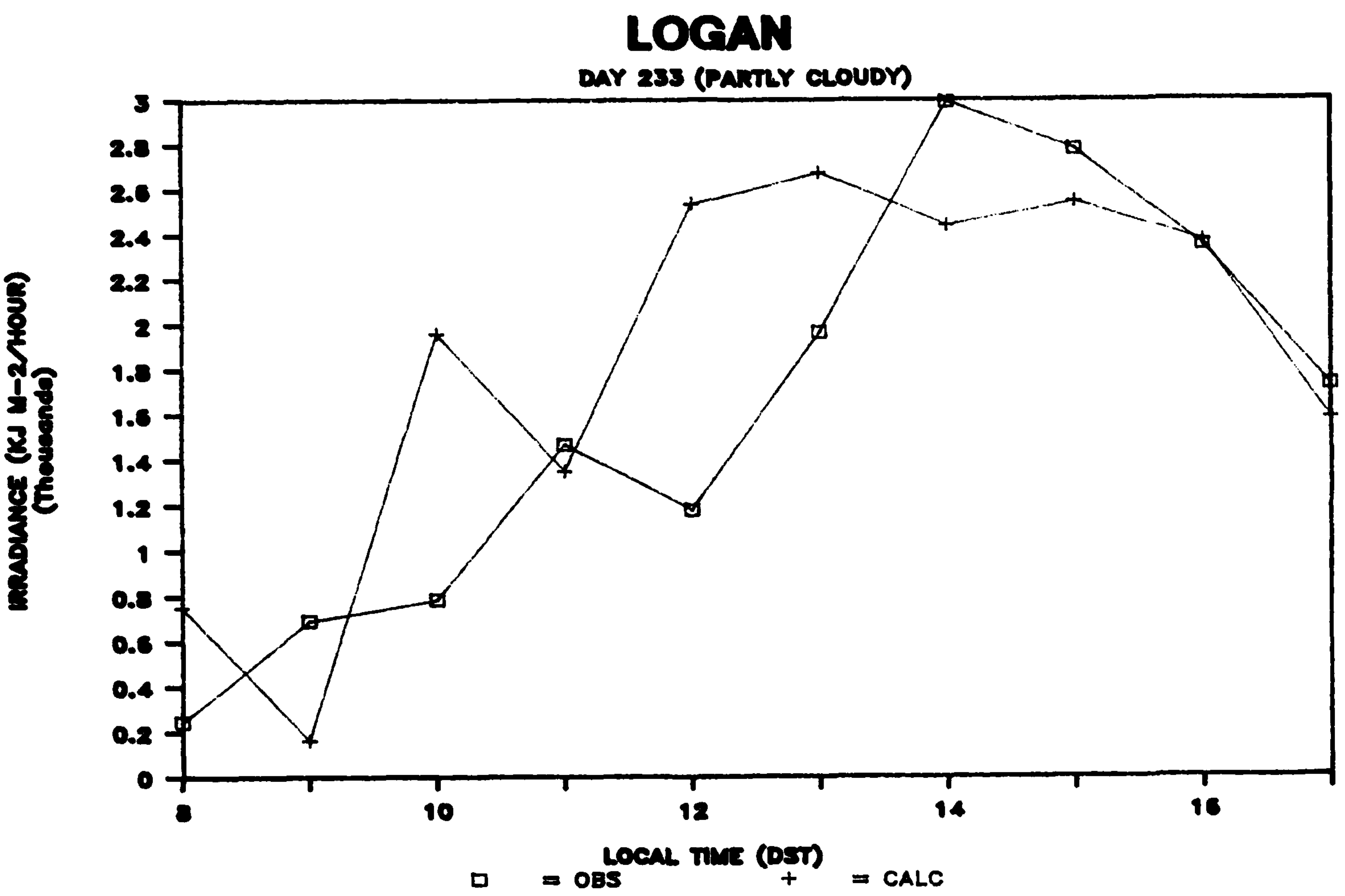


Fig. 11. Calculated and observed irradiance using the original regression coefficients from the Hay and Hanson (1978) model.

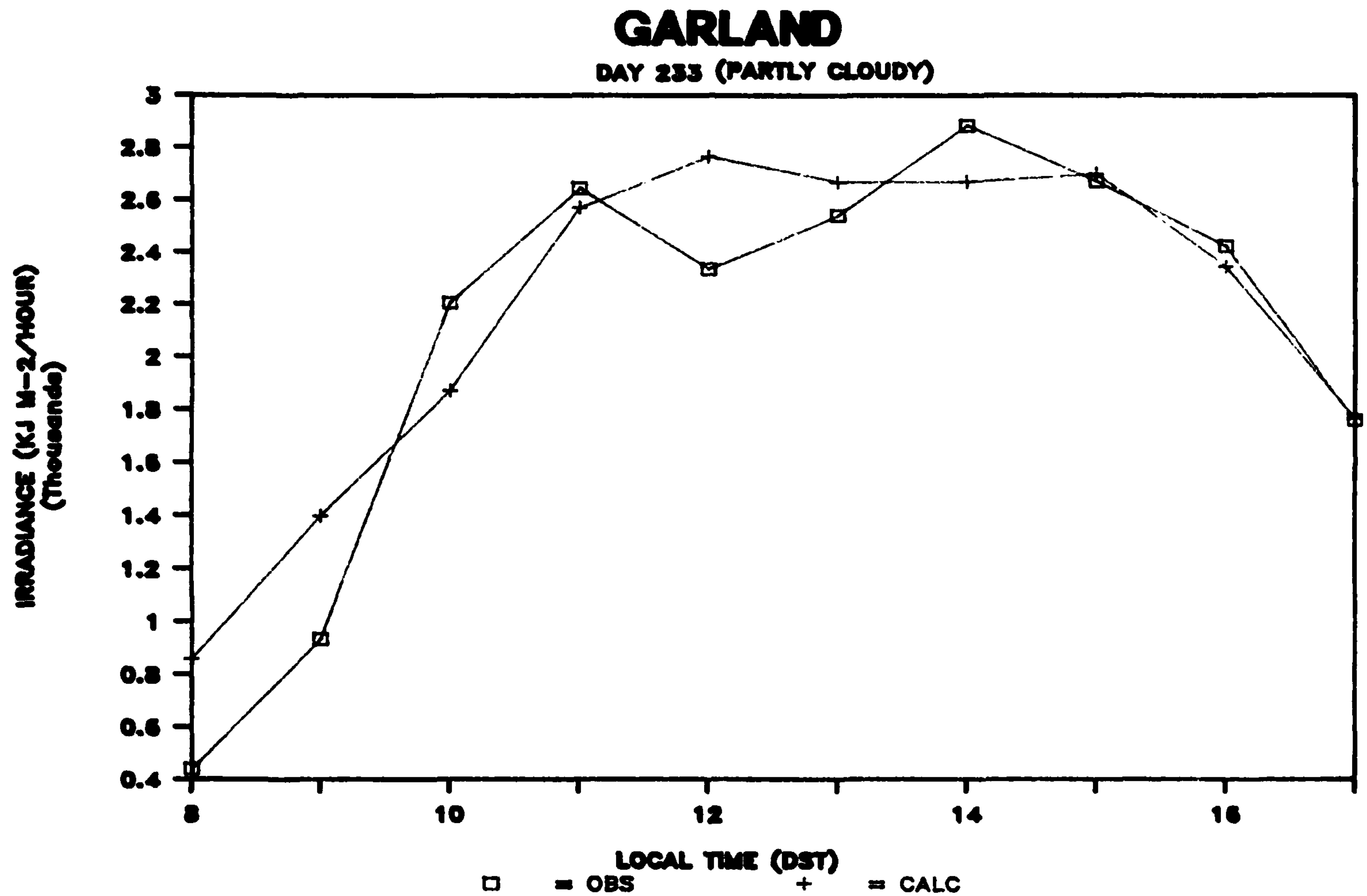


Fig. 12. Calculated and observed irradiance using the original regression coefficients from the Hay and Hanson (1978) model.

low estimates for clear days don't quite cancel out, leaving calculated values, in most cases, lower than the observed.

Figures 9 - 23, depicting partly cloudy sky conditions, reveal that the model generally mirrors the observed data line. The figures also indicate that the model tends to overestimate irradiance values during the morning and evening hours with underestimation during the mid day hours, producing a greater amount of underestimation during the mid day hours than with the mid day under estimations for clear days.

The figures depicting partly cloudy days also indicate that the model matches the late morning, evening and mid day observations quite well. However, the model has trouble with peaks and valleys in the observed data often missing major events of cloudiness or sunshine. This often produces the most erroneous irradiance calculations of the three sky cover conditions.

The fact that the model has a problem calculating irradiance values for cloudy days should come as no surprise. It must be remembered that the irradiance calculation is based on one satellite image taken at the beginning of the hour while the observed data is sampled every minute and integrated for the hour. An assumption is made that the satellite measurement taken once an hour can approximate a pyranometer measurement averaged for the same hour.

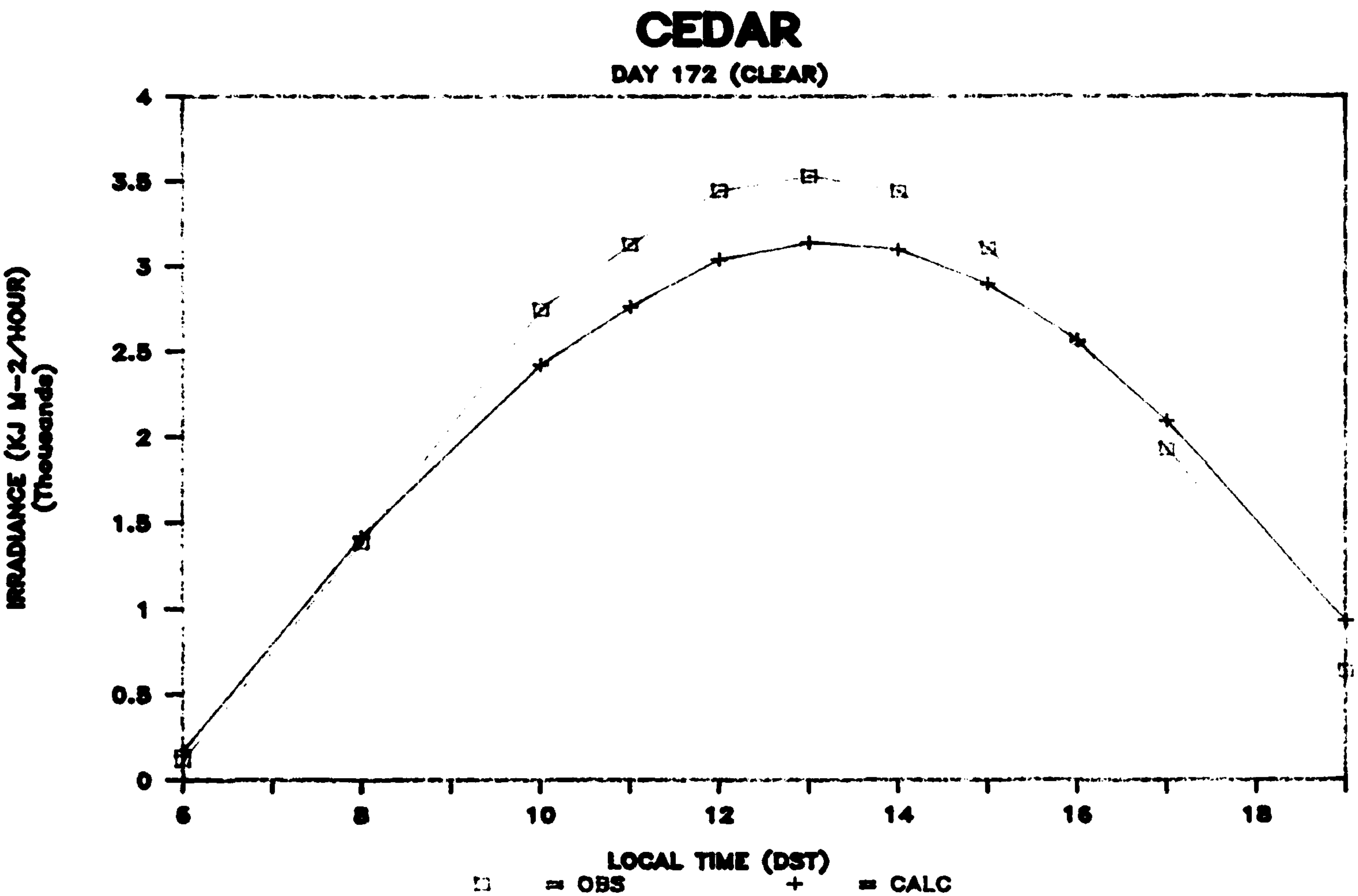


Fig. 13. Calculated and observed irradiance using the improved regression coefficients in the Hay and Hanson (1978) model.

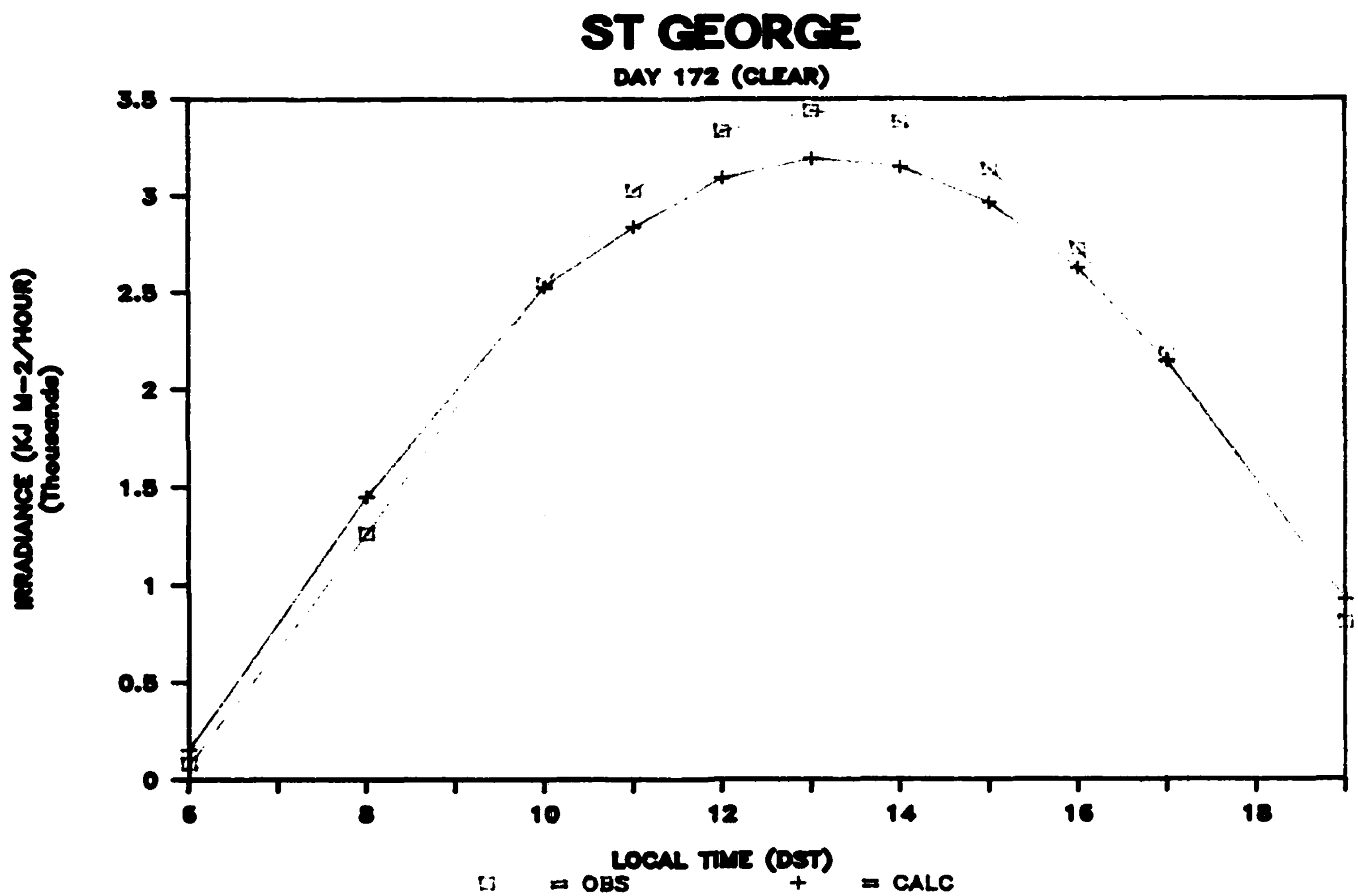


Fig. 14. Calculated and observed irradiance using the improved regression coefficients in the Hay and Hanson (1978) model.

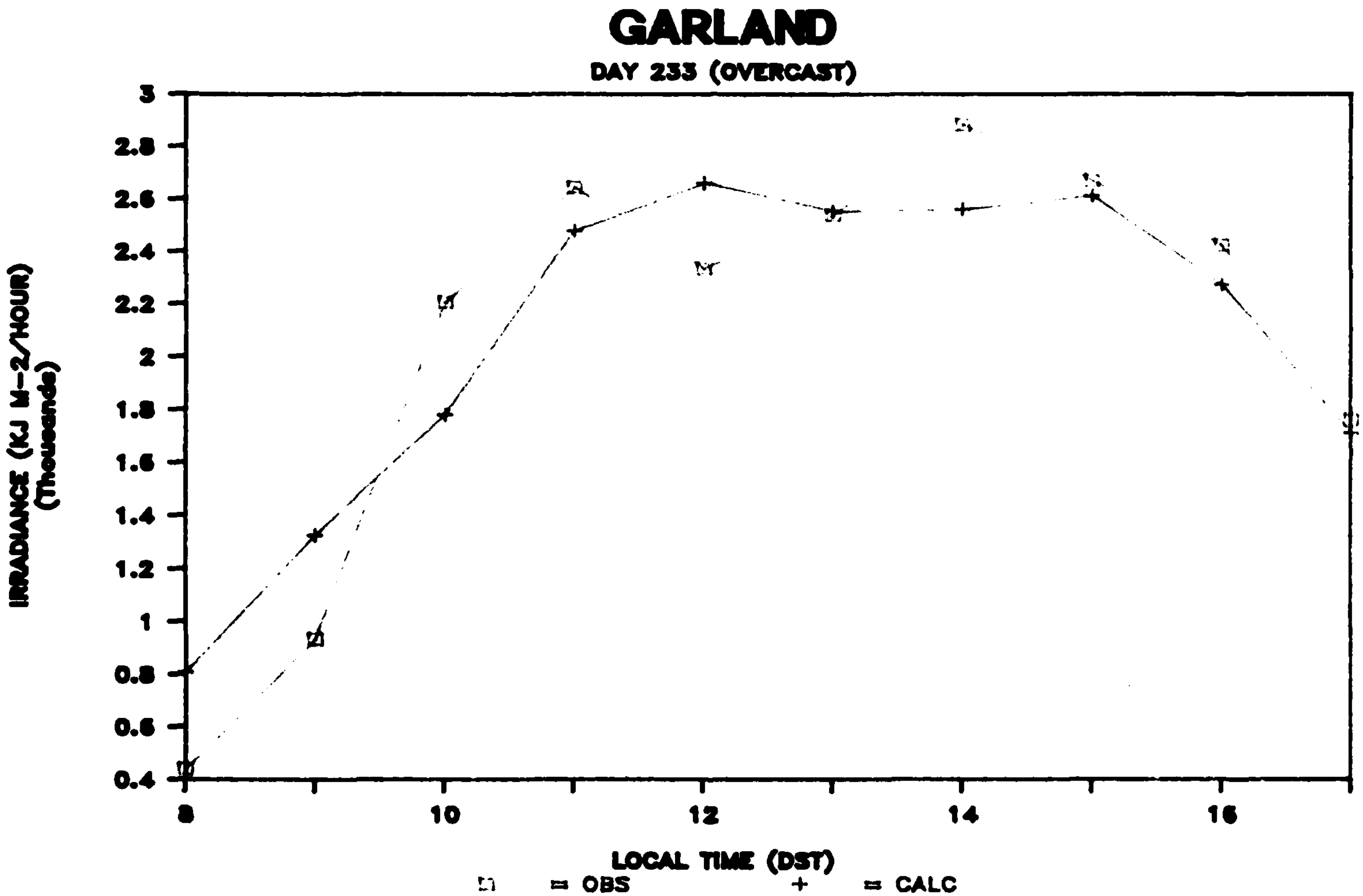


Fig. 15. Calculated and observed irradiance using the improved regression coefficients in the Hay and Hanson (1978) model.

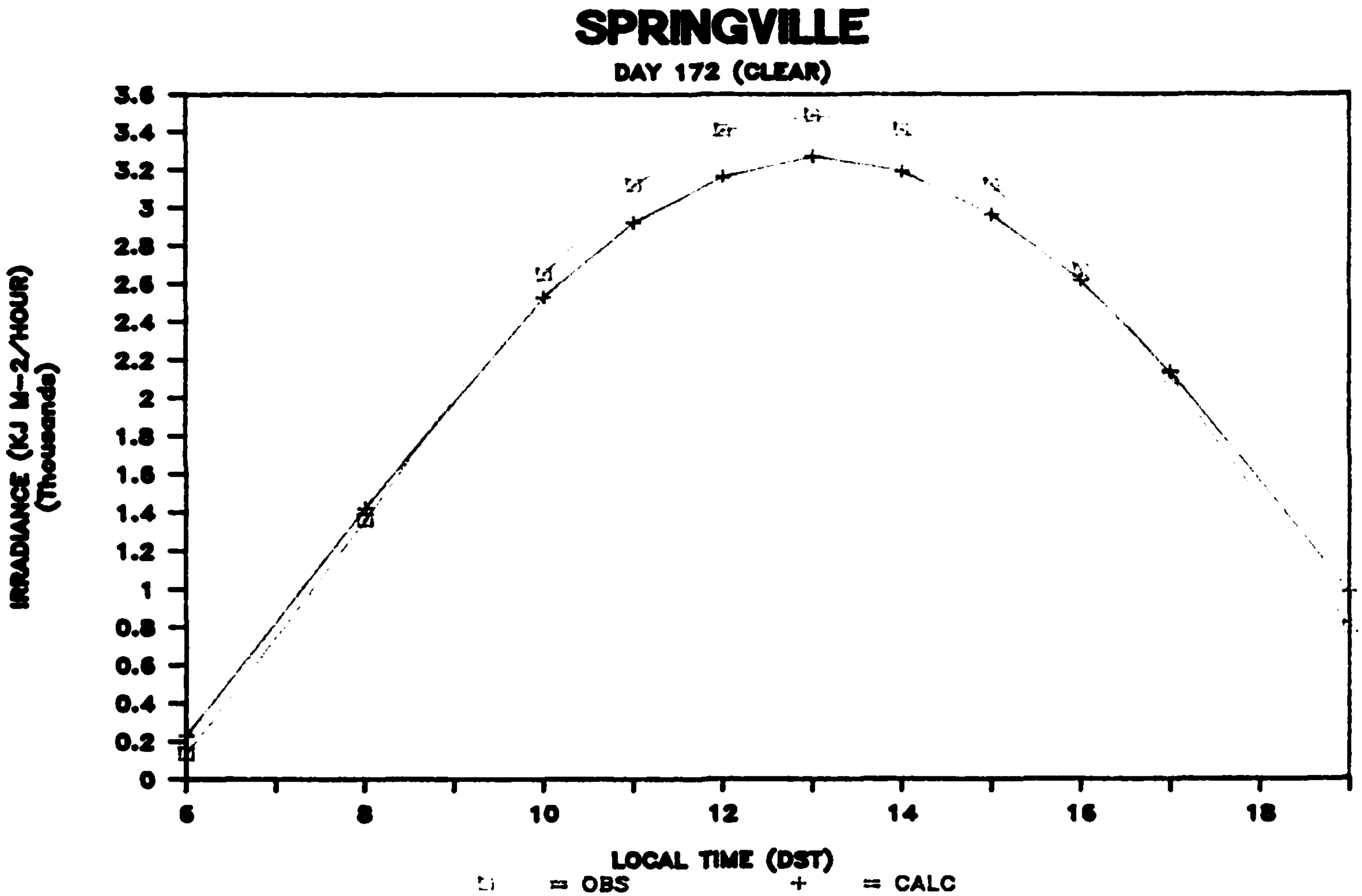


Fig. 16. Calculated and observed irradiance using the improved regression coefficients in the Hay and Hanson (1978) model.

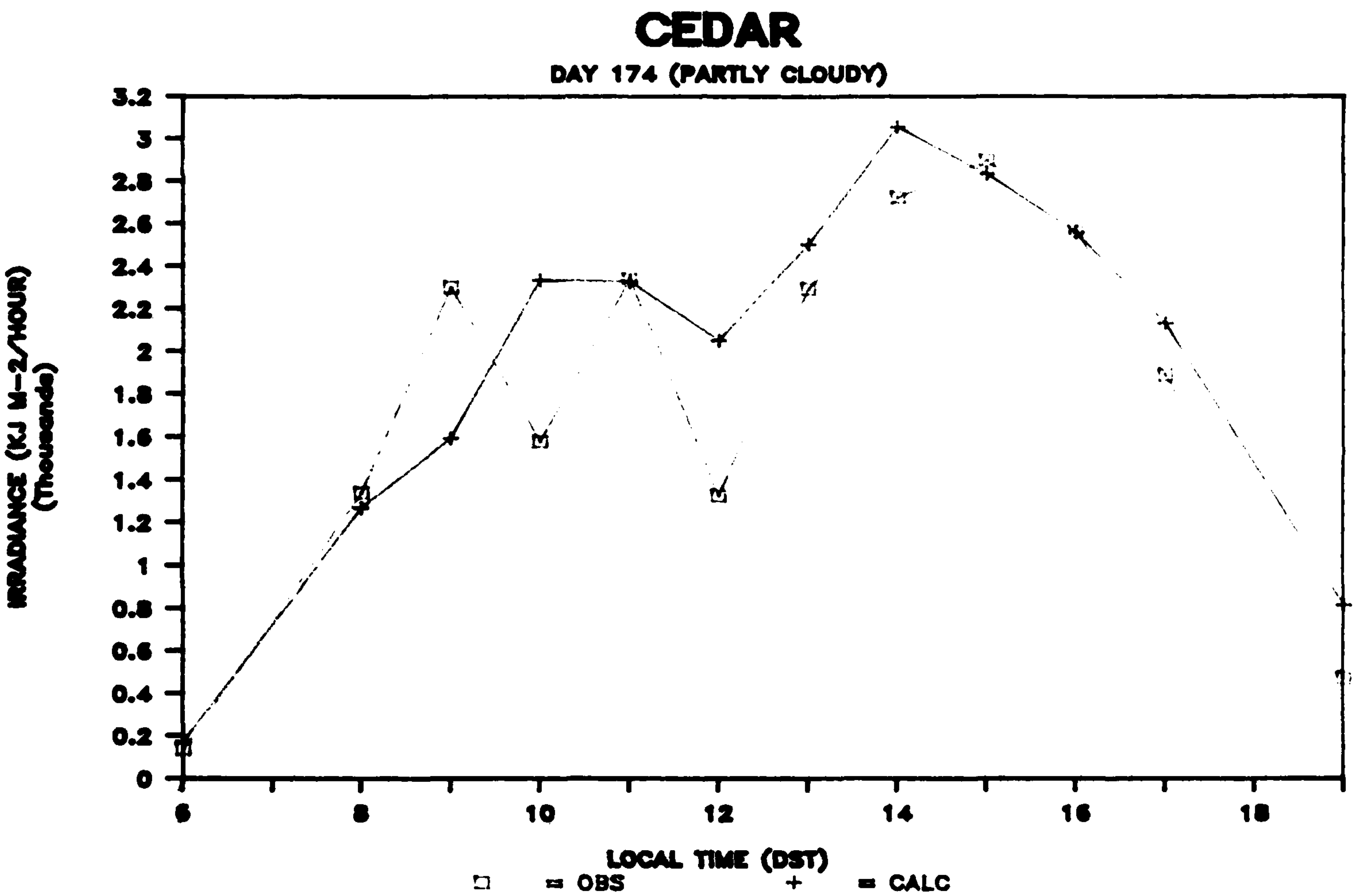


Fig. 17. Calculated and observed irradiance using the improved regression coefficients in the Hay and Hanson (1978) model.

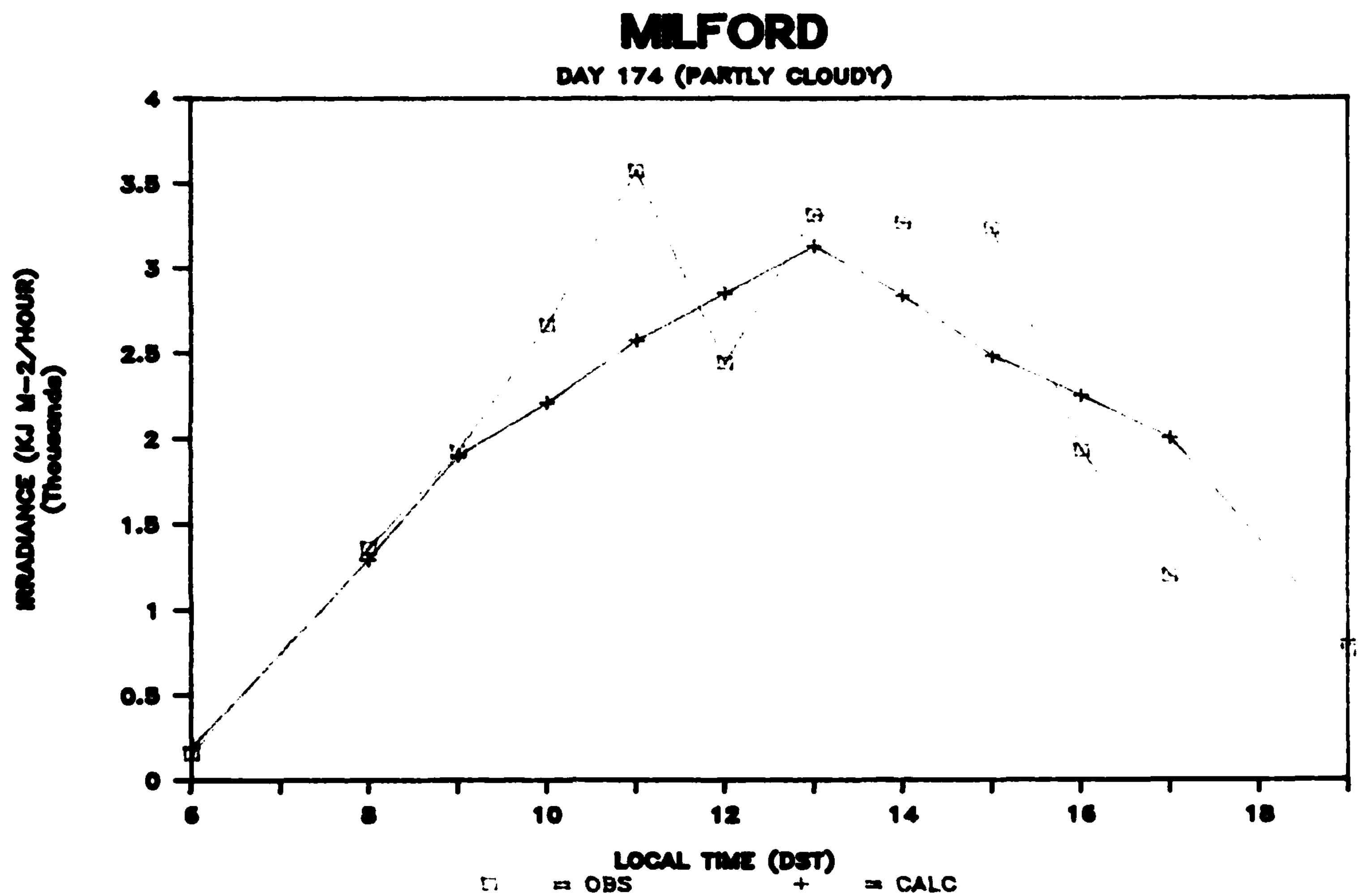


Fig. 18. Calculated and observed irradiance using the improved regression coefficients in the Hay and Hanson (1978) model.

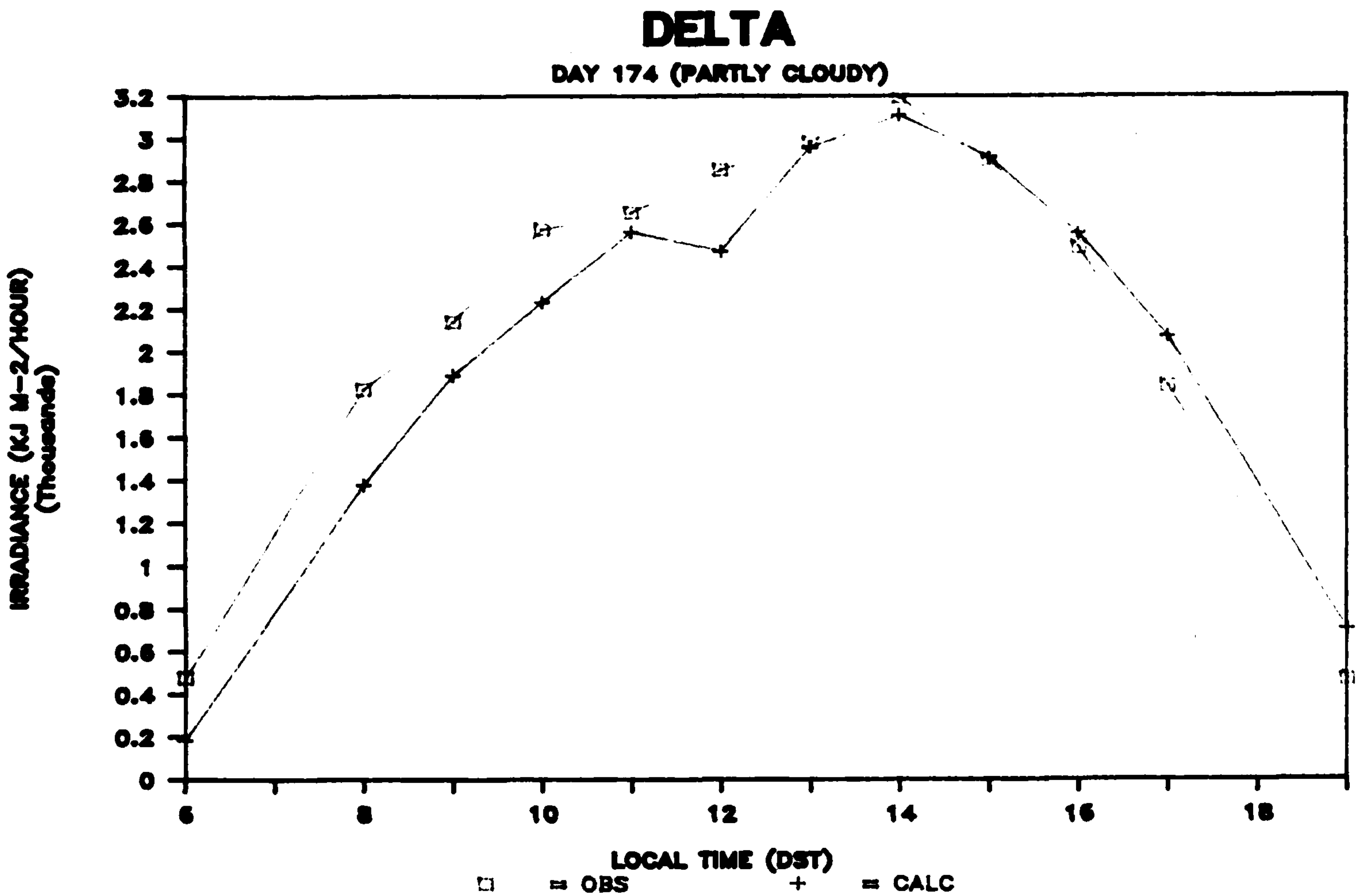


Fig. 19. Calculated and observed irradiance using the improved regression coefficients in the Hay and Hanson (1978) model.

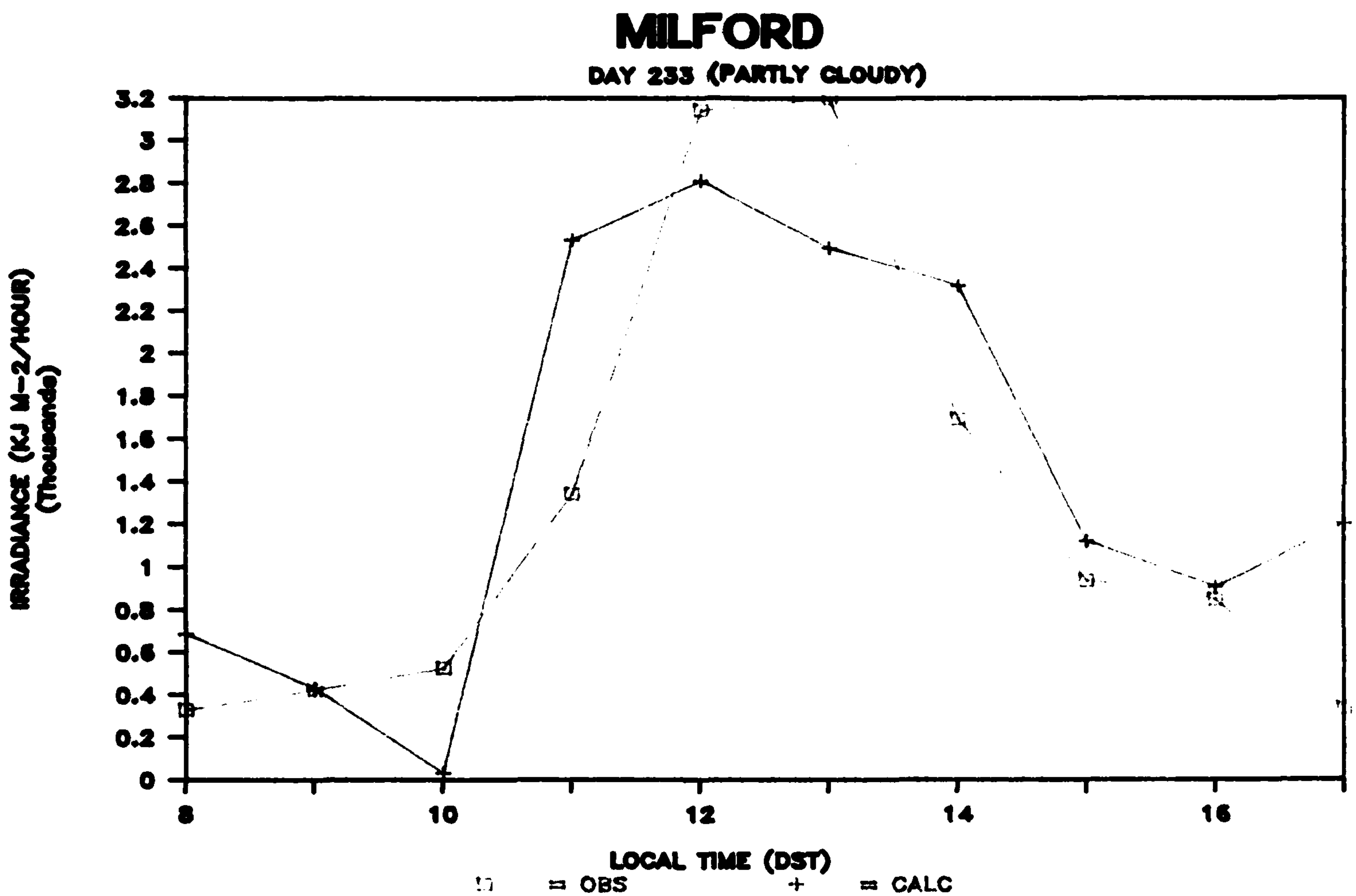


Fig. 20. Calculated and observed irradiance using the improved regression coefficients in the Hay and Hanson (1978) model.

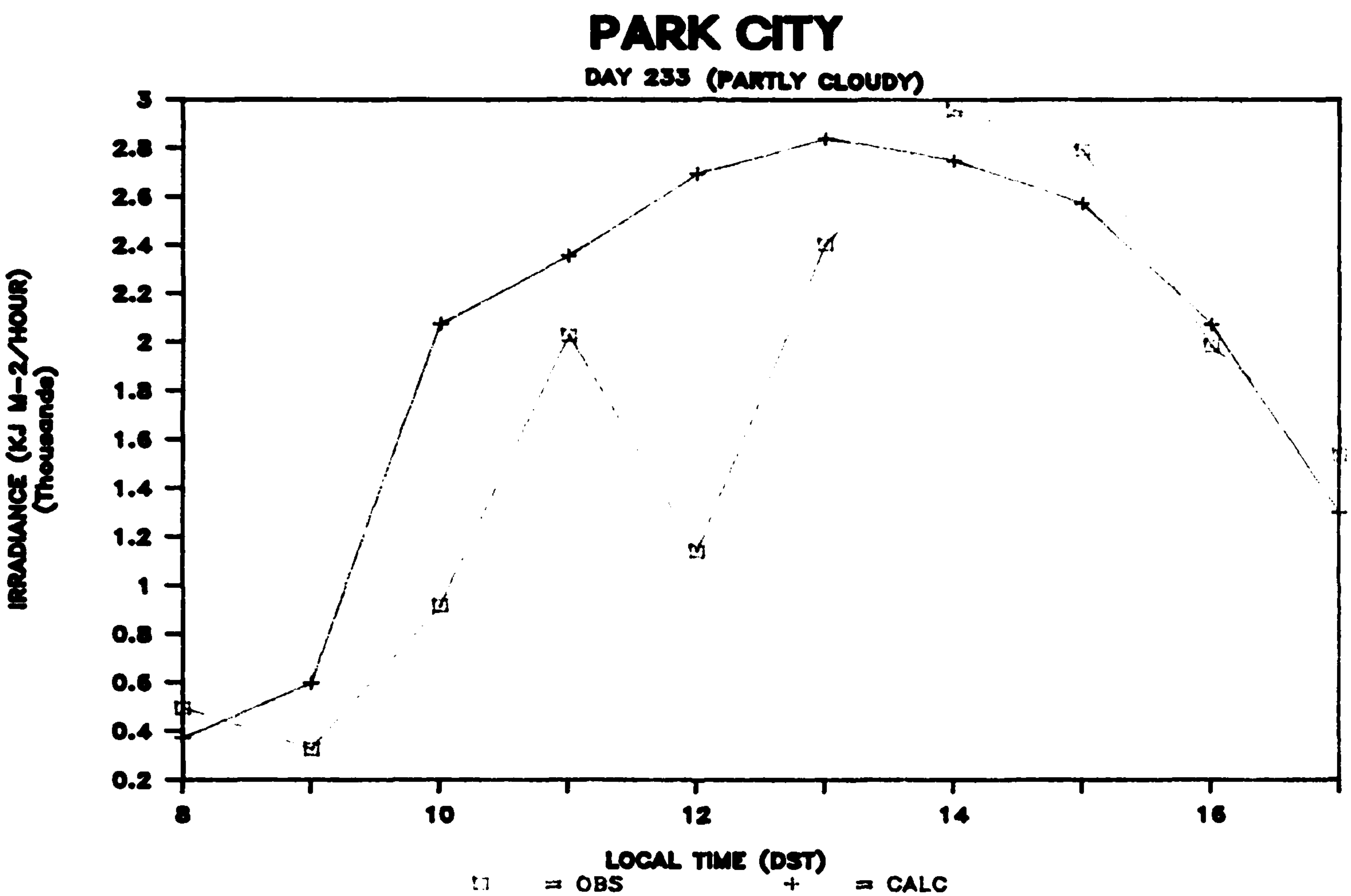


Fig. 21. Calculated and observed irradiance using the improved regression coefficients in the Hay and Hanson (1978) model.

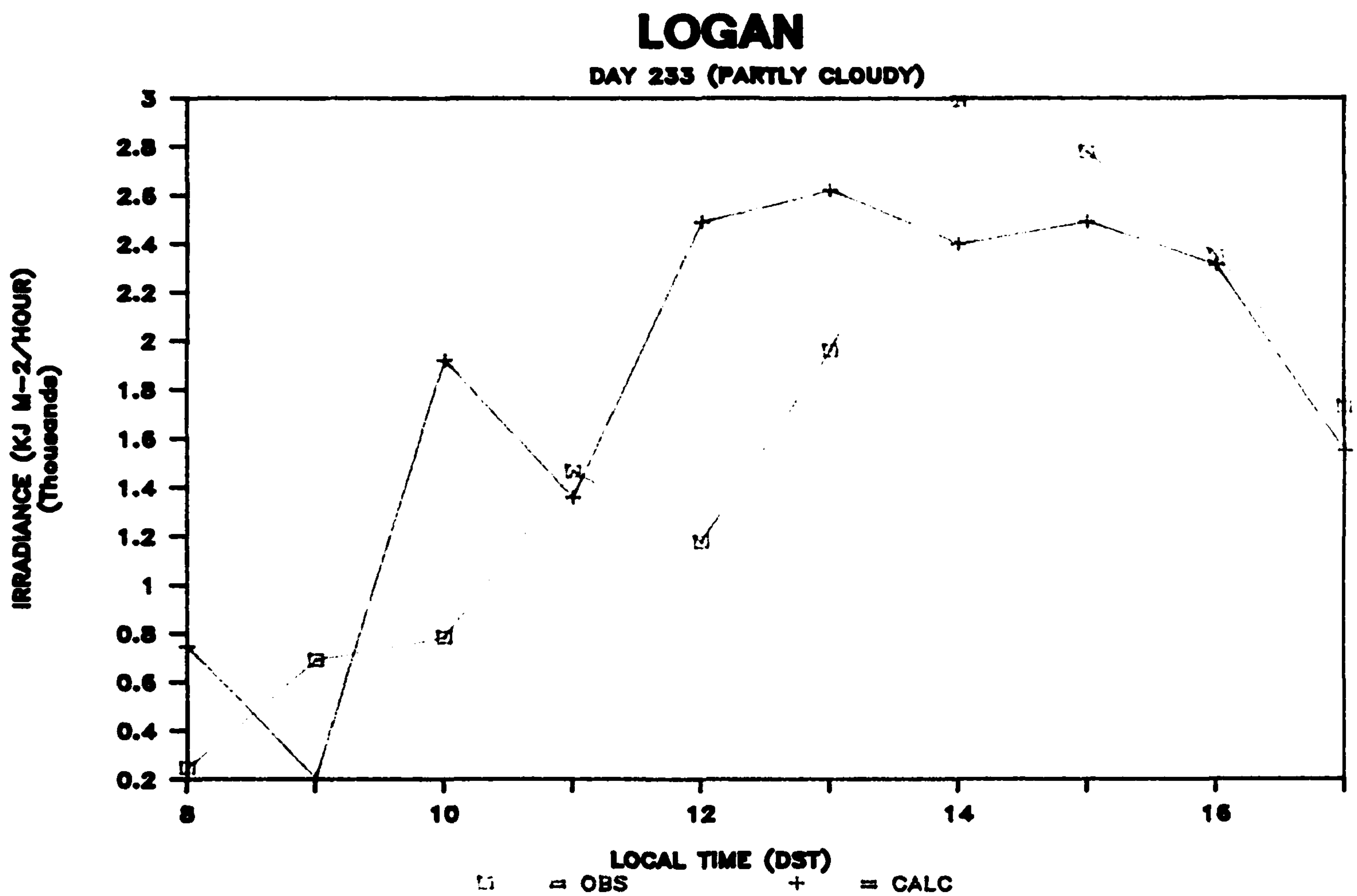


Fig. 22. Calculated and observed irradiance using the improved regression coefficients in the Hay and Hanson (1978) model.

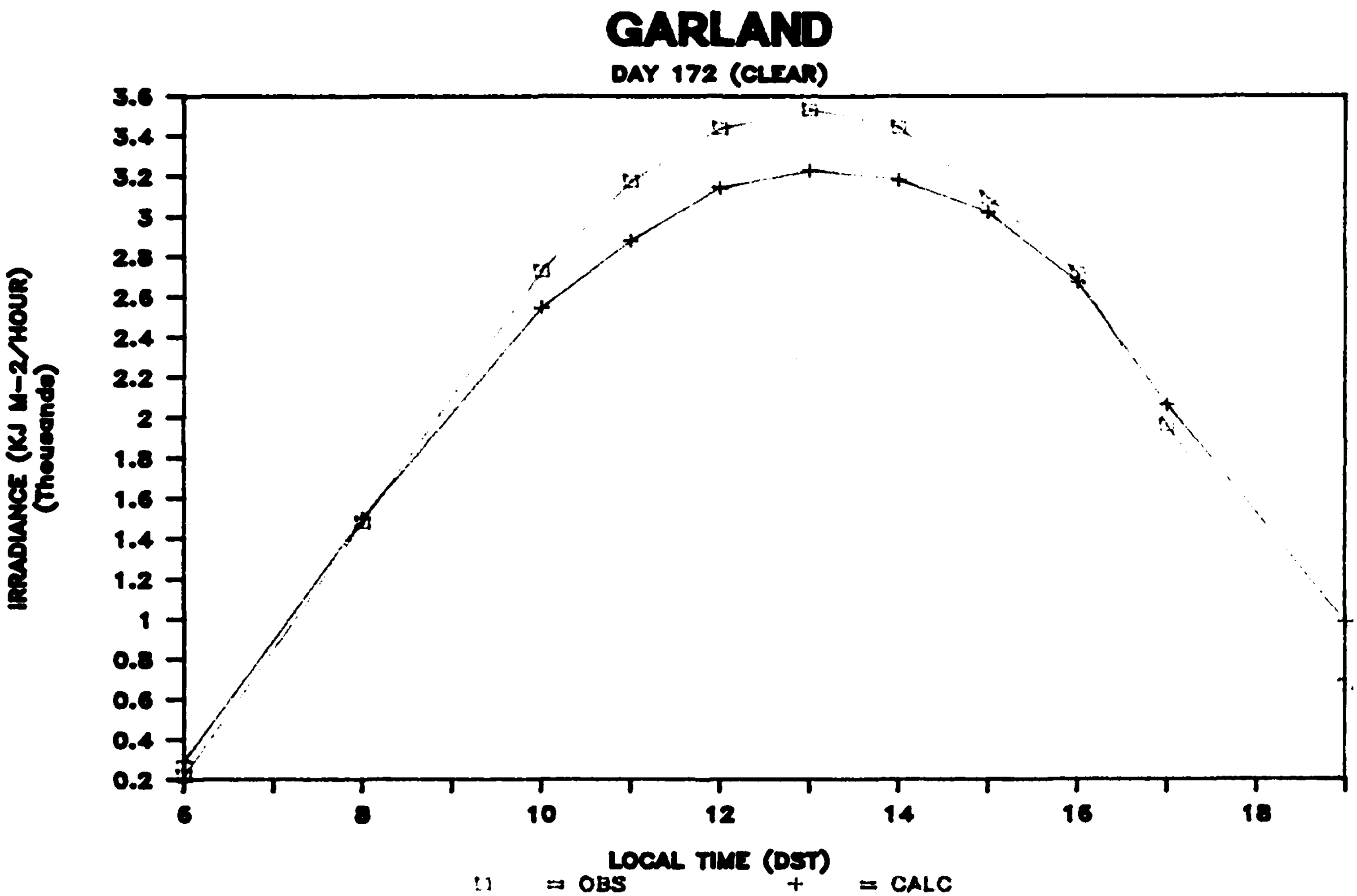


Fig. 23. Calculated and observed irradiance using the improved regression coefficients in the Hay and Hanson (1978) model.

For example, the instantaneous measurement made by the satellite may see clear skies while, in fact, the pyranometer has been shadowed by drifting clouds during the remainder of the hour. This would produce a high calculated value and a low observed value.

The accuracy of the original model was determined by running a statistical analysis of data listed in Table 4. The totaled value listed at the bottom of the table indicates the model's performance under all sky cover conditions. The original Hay and Hanson (1978) model performed surprisingly well considering where the model was developed. However, limitations in the model become apparent when it is used to calculate cloudy conditions. Although the performance of the model is acceptable for clear days, an attempt is made to improve the model's overall performance by determining new regression coefficients.

a. Regression coefficients

The development of new regression coefficients was accomplished using data collected at four of the study sites. The sites utilized in the analyses are Cedar City, Milford, Garland and Springville. The sites were selected to represent various conditions (elevation, latitude, longitude, etc.) over the network. The analysis centered on days 172, 174, and 233 to represent various sky cover conditions. The new coefficients were calculated using an

available software package called Number Cruncher. They are determined to be: a = 0.77 and b = -0.74. Both regression coefficients changed only slightly from the values used in the original model. The old and new regression coefficients are listed in Table 5.

The original Hay and Hanson model was developed for use over the tropical Atlantic and predominately for use during the summer months. Several considerations exist when implementing the model at mid-latitude locations such as Utah. The major considerations are latitude, elevation, predominate cloud type, cloud absorption, and lower amounts of water vapor. Of these three considerations, the biggest contributer to variability in the model could be lower water vapor amounts.

b. The revised model results

The revised model was also tested over all the sites using all the available days from the data sets. The hourly average statistics, at select sites, for days 172, 174 and 233 are listed in Table 6 (see Appendix for complete statistics on the individual stations).

The effect of the revised regression coefficients for all sky cover conditions can be seen when the totaled irradiance calculations from Tables 4 and 6 are compared. The mean bias error has been considerably decreased and noticeable improvement is observed in most of the model calculations.

Table 5. The original and revised regression coefficients as developed for this study.

COEFFICIENT	ORIGINAL	REVISED
a	.79	.77
b	-.71	-.74

Table 6. The hourly statistics using the revised regression coefficients from the Hay and Hanson (1978) model for clear (day 172), and partly cloudy (days 174, 223) sky conditions.

	IRRADIANCE					
DAY	OBS	CALC	N	MBE%	RMSE%	LOCATION
172	26049.0	24550.3	11	3.8	13.0	CEDAR CITY
172	25942.9	25079.4	11	3.4	11.4	ST. GEORGE
172	26494.1	25545.0	11	3.7	12.3	GARLAND
172	26305.7	25461.2	11	3.3	11.0	SPRINGVILLE
174	21890.3	23668.7	12	-7.5	26.0	CEDAR CITY
174	25847.0	24559.1	12	5.2	18.2	MILFORD
174	26418.6	25060.6	12	5.4	18.8	DELTA
233	12459.4	13347.9	9	-6.7	20.0	MILFORD
233	15059.9	18346.5	9	-17.9	53.7	PARK CITY
233	14469.1	16566.9	9	-12.7	38.0	LOGAN
233	19094.4	19078.8	9	.1	.2	GARLAND
TOT:	240030.4	241264.4	116	-.5		

From the results in Table 6 and those listed in the Appendix, the improvement in the MBE% and RMSE% values for partly cloudy days indicate the performance of the model for this type of day has been improved. The smaller value for the coefficients means that the mid day estimations would decrease with slightly higher estimations during the morning and evening hours. This trend would be most beneficial at sites that experience cloudy conditions during the peak insulation period.

Figure 17 shows such a situation. The conditions at Cedar City on day 174 indicate that the site began the day cloud free and received the normal amount of irradiance for such a condition. During mid morning, convective clouds began to develop and remained through the mid day hours, not allowing the site to receive the maximum amount of irradiance. The site again became cloud free during the evening hours and then followed a clear sky trend. For this situation, the revised model produced estimates that were slightly high during the morning and evening hours, which is similar to a clear day. The mid day estimates were similar to a cloudy day. The two combinations help to balance the estimates produced for this type of day.

The days that showed no improvement can be characterized in two ways. First, the site had widely divergent cloud conditions from hour to hour. In a case such as this, one satellite image per hour would be a poor indicator of the

conditions experienced at the site. Second, the site experienced cloud free conditions during the mid day hours and was allowed to receive the same, or nearly the same, irradiance as a clear site. Most of the sites that show no improvement appear to follow the first case.

For the clear day, the overall effect of the smaller regression coefficients was to reduce the estimated irradiance values in the model. Figures 13-16 show that the revised regression coefficients do not change the shape of the curve for the calculated values, only the height at which the curve peaks. This helped to lower the morning and evening overestimations but it also added to the mid day underestimations. This resulted in higher MBE% and RMSE% values. The magnitude of the reduced performance for a clear day is small and since the majority of the days in the study are cloudy the reduced performance of the model for clear days is acceptable.

c. Dav 232

Nearly every site experienced one or two days that were not handled well by the model. Satellite analysis and ground observations indicate that a thin band of cirrus traversed across the state during day 232. The daily tables indicate that day 232 was a problem day shared by most of the sites in the network and that the model tends to considerably overestimate a thin cirrus condition.

The daily results (Appendix) for day 232 indicate consistently poor MBE and RMSE values across the network. Correlation coefficients range from as low as -.0515 at Logan to .8581 at Springville with the majority of the R values at .6 or lower. Due to the consistently poor results over the entire network, it appears the model has some problem calculating accurate irradiance values for days with a thin cirrus overcast.

d. Summary

This initial test of the Hay and Hanson (1978) model has shown that the regression coefficients developed for the tropical Atlantic were not completely suitable for the data used in this study, but the fit is remarkably good considering where the model was developed. The error is due to the bias of this data set to partly cloudy and overcast conditions and the higher elevations experienced over the network.

Revised regression coefficients lead to increases in performance for partly cloudy sky cover conditions. Although overcast conditions were never experienced over the entire network. The results indicate the model seems to considerably overestimate a heavy cloud condition.

Under clear skies, the pattern of over and under estimates observed in the initial test of the model was maintained with increased underestimation during the mid day

hours. This leads to a slight decrease in performance for clear sky conditions. For operational use of this model at these elevations the basic shape function in the look-up table needs to be modified.

The performance of the model for partly cloudy conditions showed improvement at sites that were cloudy during the mid day hours. The model continues to experience trouble calculating irradiance values when the site changes widely from hour to hour due to cloud shadowing or cloud movement.

2. The Tarpley model

An aspect of some importance to this study is that the model be applied to the data set as developed by the original developer. This guarantees that any differences in results cannot be attributed to changes in the model and must reflect the different environments. There are, however, several differences from the original Tarpley model and the one utilized here.

One difference between the two models is the brightness scale used in the satellite data. A 6-bit scale is used in the Tarpley (1979) study with count values from 0 - 63. In the present study an 8-bit scale is utilized with count values from 0 - 255. This requires that several values within the model be multiplied by a factor of 4 to make the two scales compatible.

An additional difference is the source of the precipitable water values necessary for the irradiance calculations. The values used in the Tarpley (1979) study were accessed from the National Meteorological Center (NMC) 0000 GMT operational file. Accessing routines retrieved precipitable water for each site from the nearest NMC grid point which could be as far as 2 latitude and longitude from the station (Tarpley, 1979). In this study the precipitable water values were calculated for each hour with Smith's (1966) empirical formulation using temperature and dew point data available from each site. Although the model is not very sensitive to precipitable water, this method could permit a more accurate assessment of the model.

The initial test of the Tarpley (1979) model was performed over all the test sites. Prior to the test, Julian days 172, 174, and 233 were selected for analysis representing clear, partly cloudy and overcast sky conditions, respectively. The hourly calculations for the three days were compared to the measured irradiance values at all the sites in the study. Complete statistics for the sites are listed in the Appendix, while averaged hourly statistics for a few select locations are given in Table 7. Figures 24 - 33 depict the behavior of the model for the days and sites in Table 7. As with the Hay and Hanson (1978) model, the initial test indicated no bias towards any of the test sites.

Table 7. The hourly statistics at select sites using the original regression coefficients from the Tarpley (1979) model for clear (day 172), and partly cloudy (days 174, 233) sky conditions.

	IRRADIANCE					
Day	OBS	CALC	N	MBE%	RMSE%	LOCATION
172	26049.0	26782.4	11	-2.7	9.1	CEDAR CITY
172	25942.9	26954.6	11	-3.8	12.4	ST. GEORGE
172	26494.1	26760.0	11	-1.0	3.3	GARLAND
172	26305.7	26825.3	11	-1.9	6.4	SPRINGVILLE
174	20562.5	22582.9	11	-8.9	29.7	CEDAR CITY
174	23403.2	23598.8	11	-.8	2.7	MILFORD
174	23564.4	24777.9	11	-4.9	16.2	DELTA
233	12459.4	14712.7	9	-15.3	45.9	MILFORD
233	15059.9	20117.2	9	-25.1	75.4	PARK CITY
233	14469.1	18254.3	9	-20.7	62.2	LOGAN
233	19094.4	21182.8	9	-9.9	29.6	GARLAND
TOT:	233404.6	252548.9	113	-7.5		

The averaged hourly calculations from the initial test indicate that the model generally overestimates the observed irradiance values for most conditions.

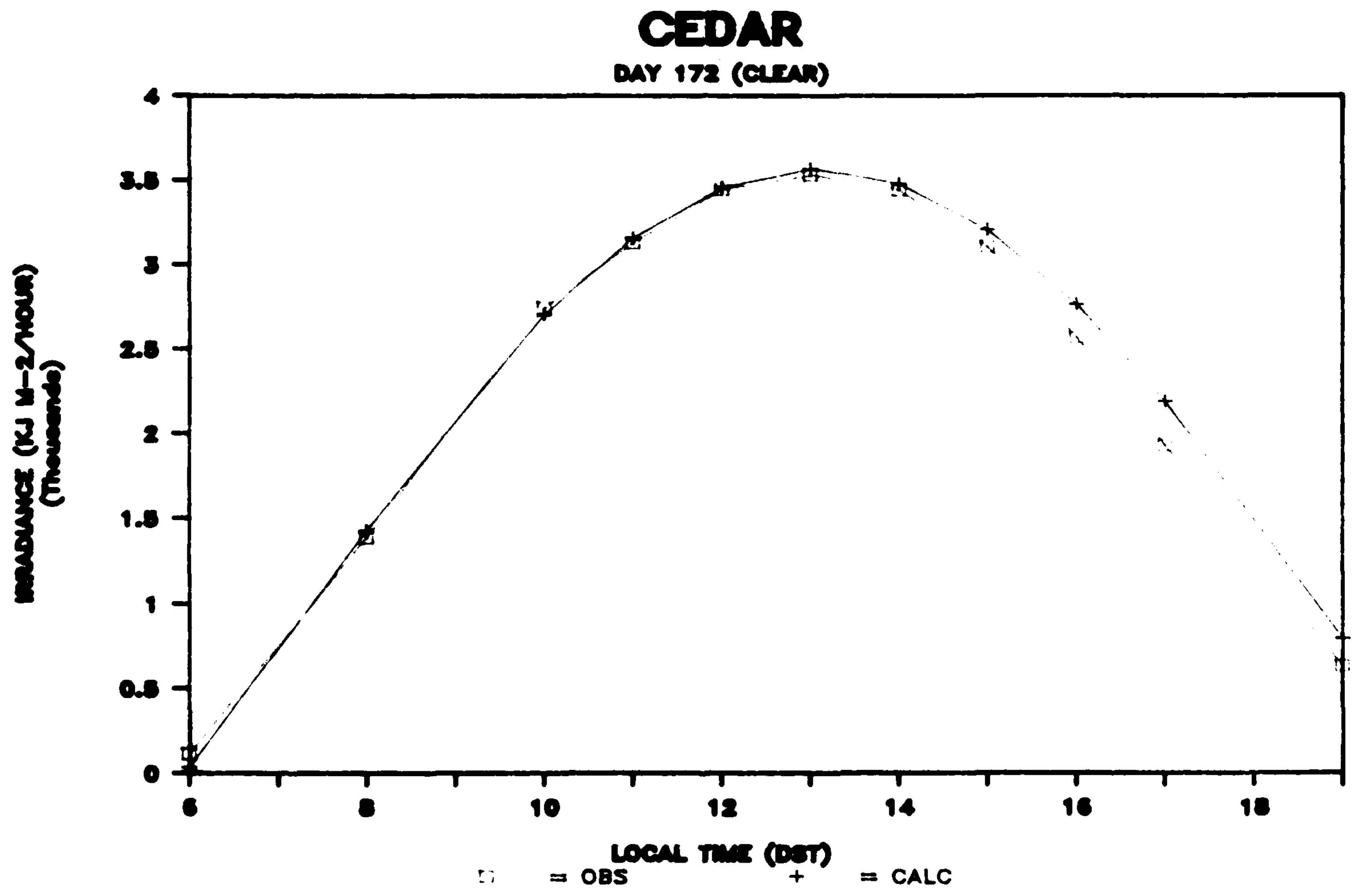


Fig. 24. Calculated and observed irradiance using the original regression coefficients from the Tarpley (1979) model.

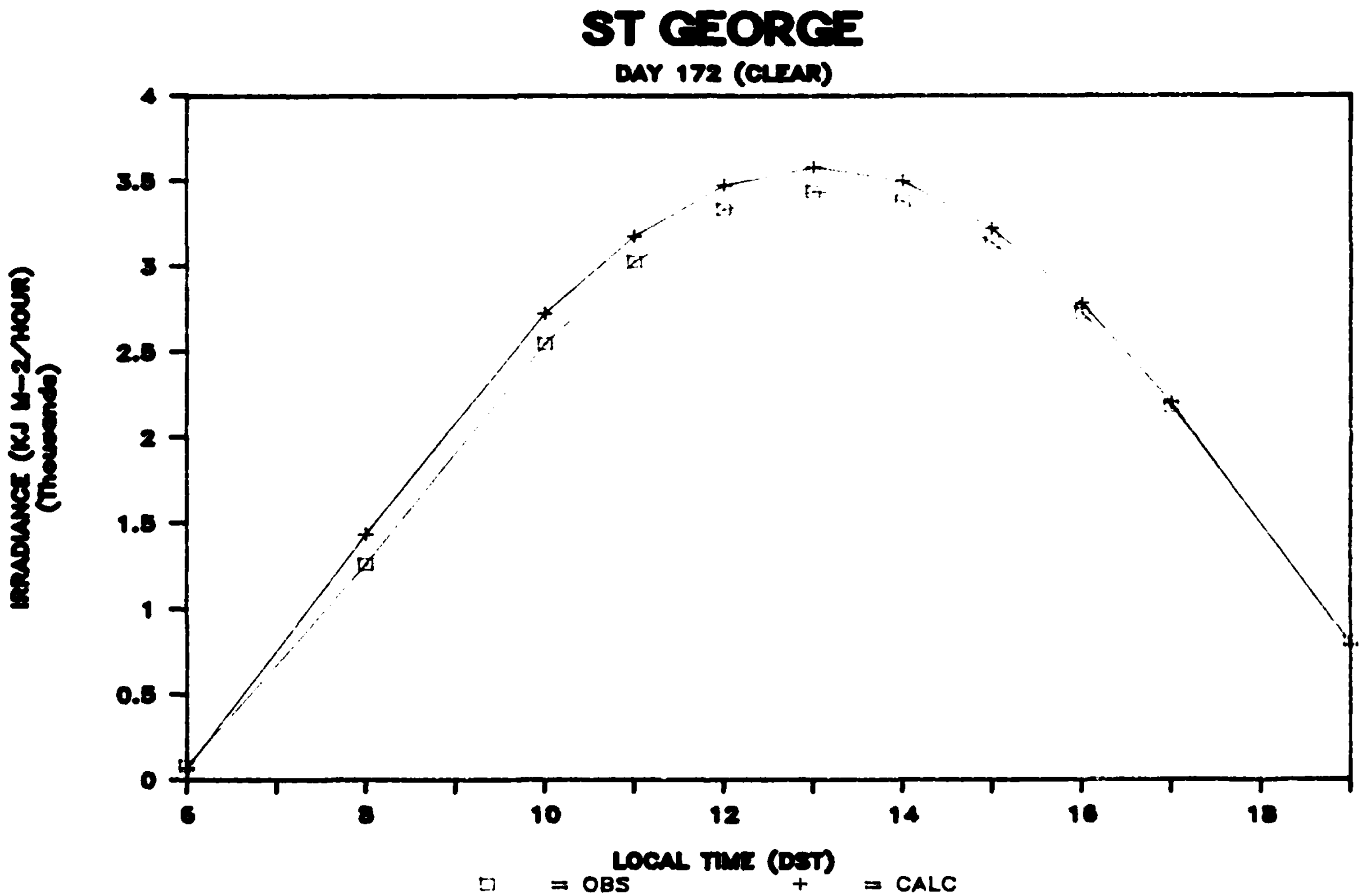


Fig. 25. Calculated and observed irradiance using the original regression coefficients and the Tarpley (1979) model.

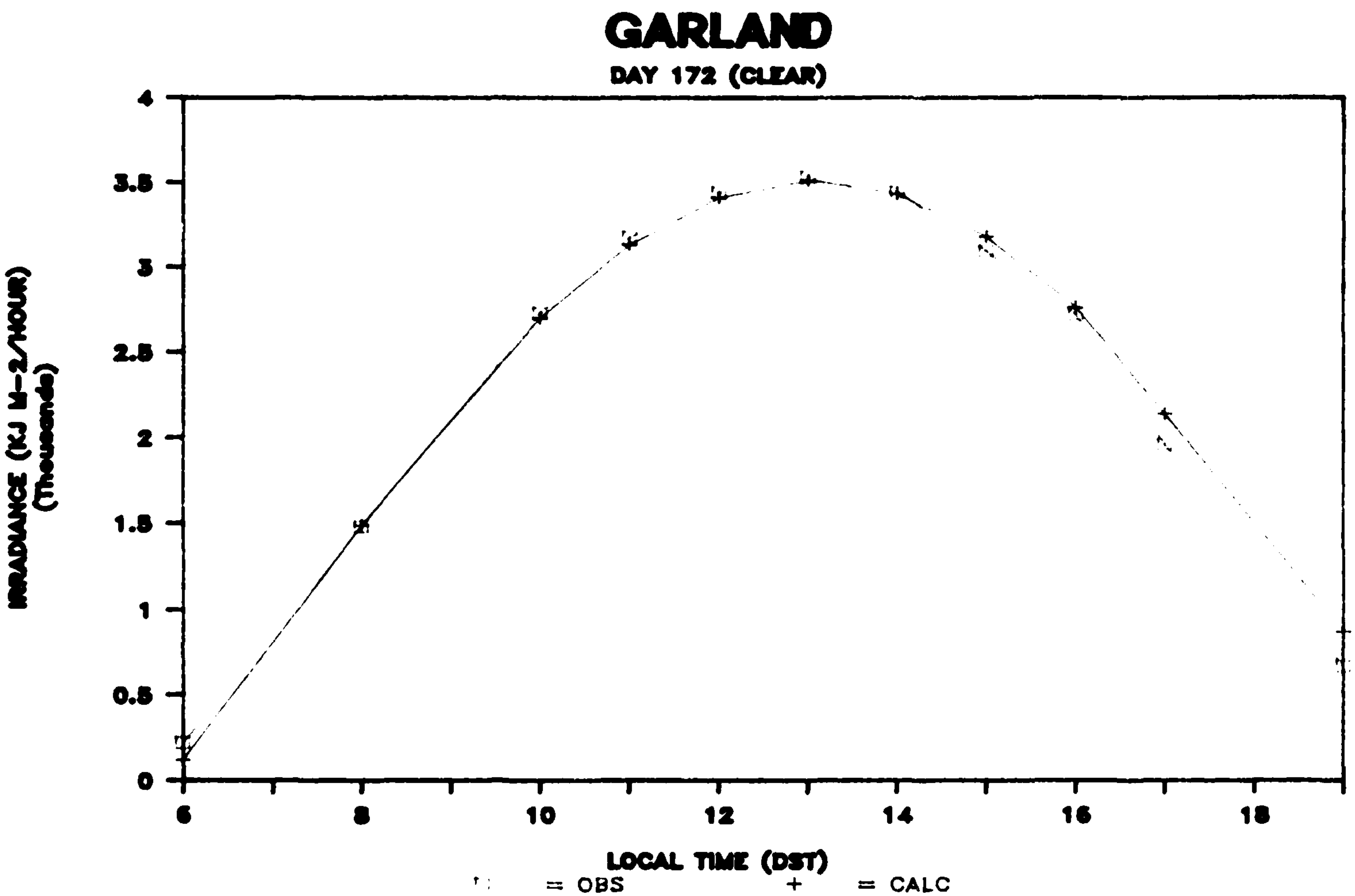


Fig. 26. Calculated and observed irradiance using the original regression coefficients from the Tarpley (1979) model.

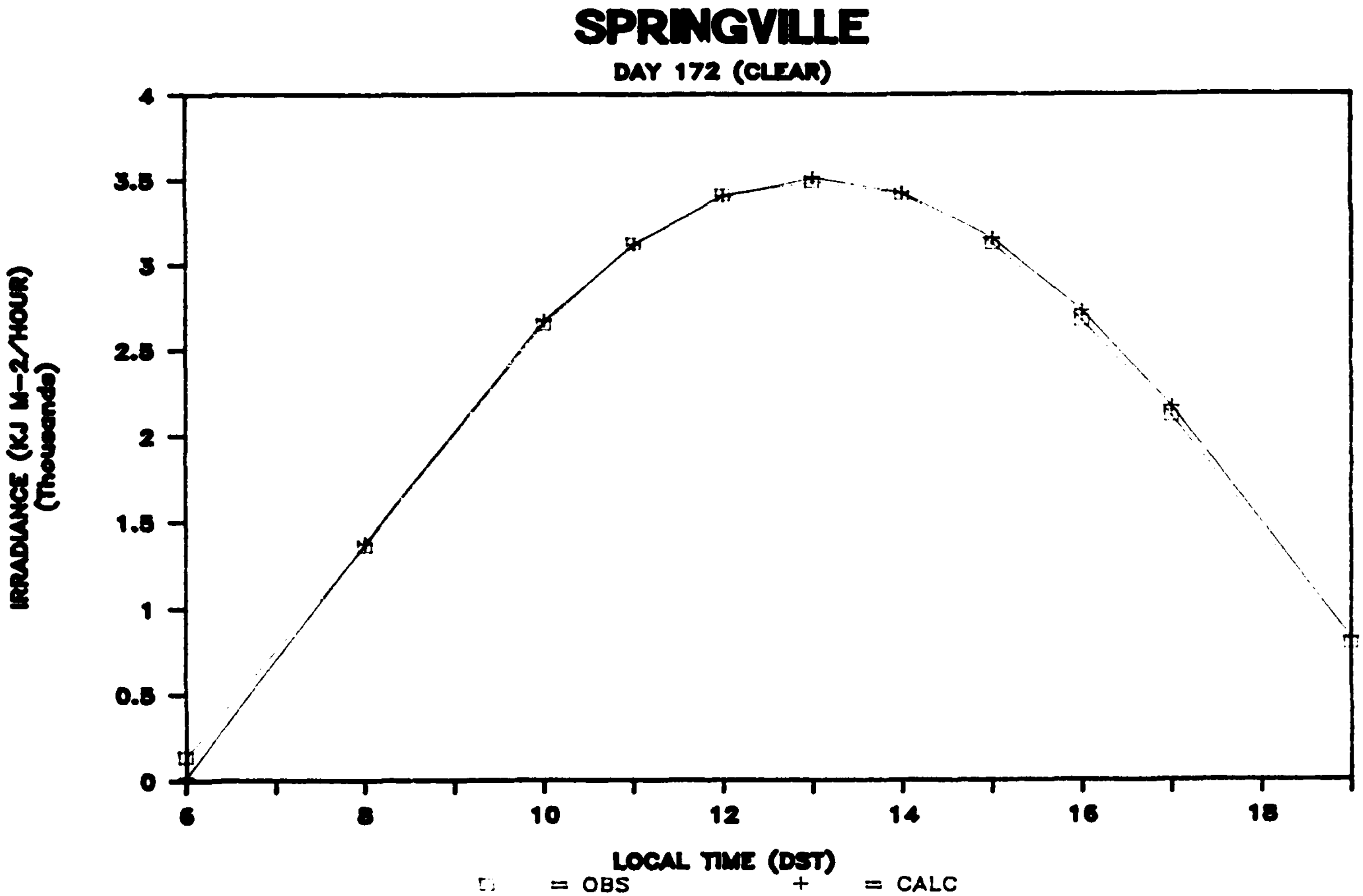


Fig. 27. Calculated and observed irradiance using the original regression coefficients from the Tarpley (1979) model.

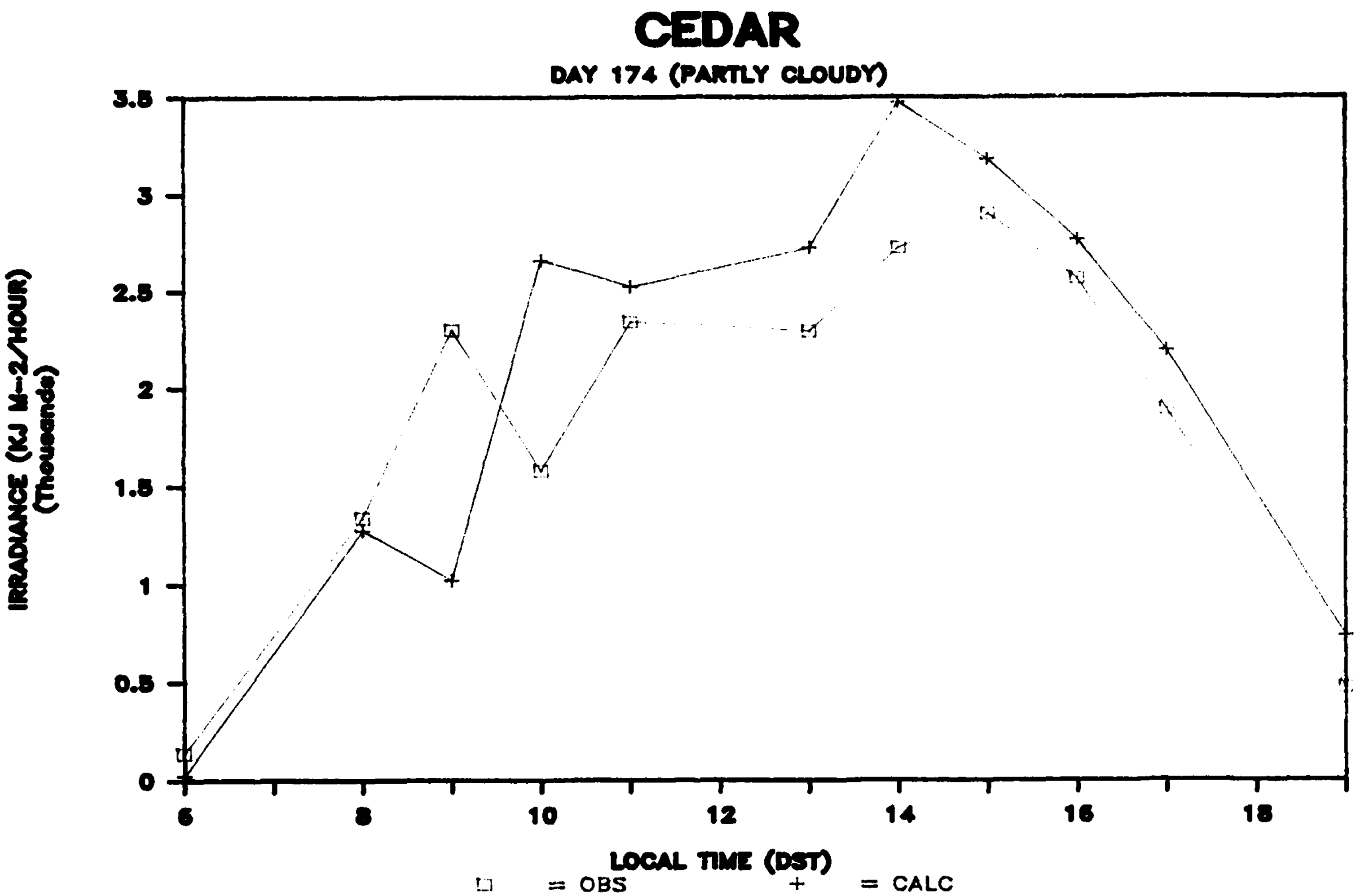


Fig. 28. Calculated and observed irradiance using the original regression coefficients from the Tarpley (1979) model.

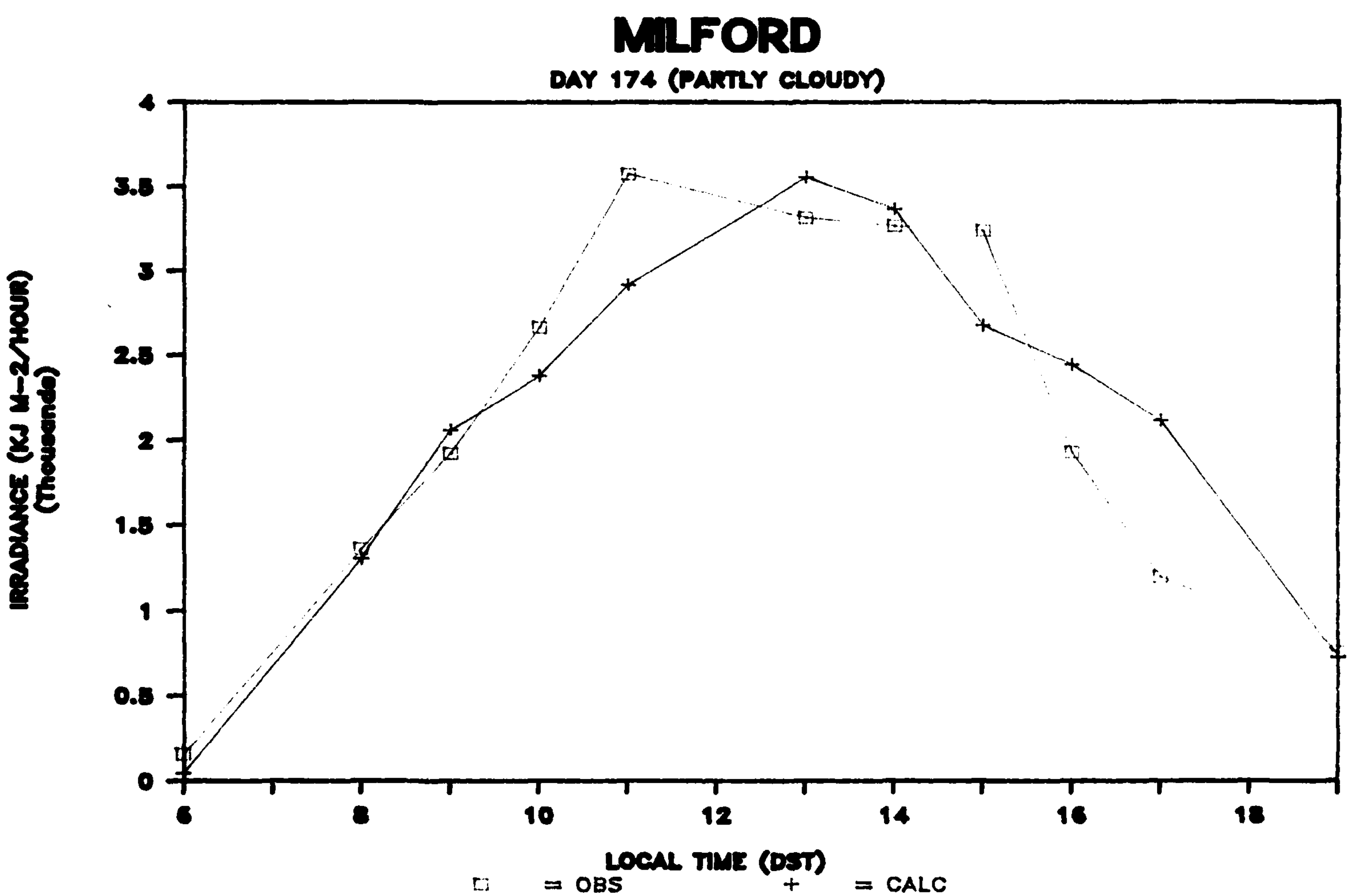


Fig. 29. Calculated and observed irradiance using the original regression coefficients from the Tarpley (1979) model.

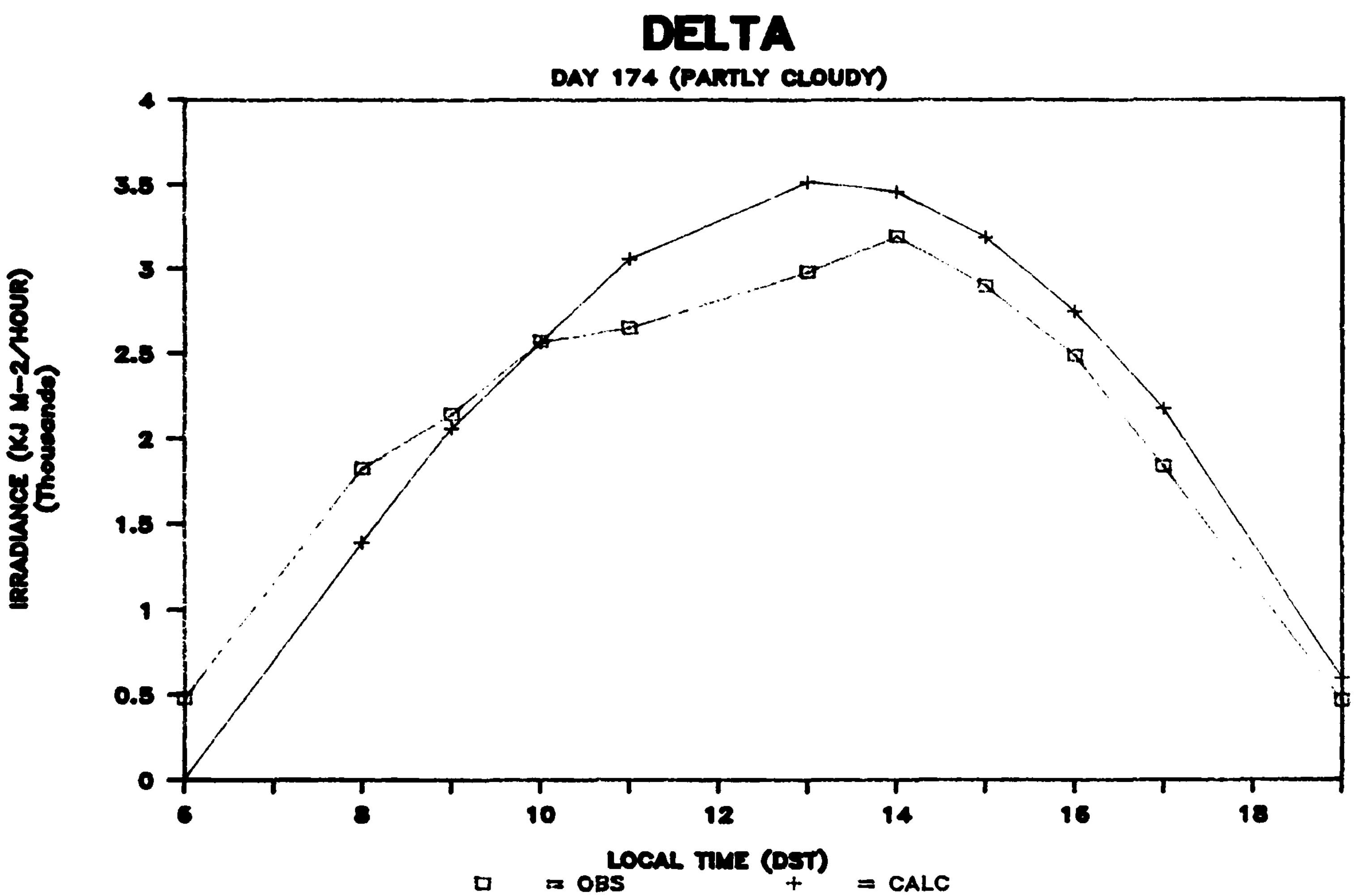


Fig. 30. Calculated and observed irradiance using the original regression coefficients from the Tarpley (1979) model.

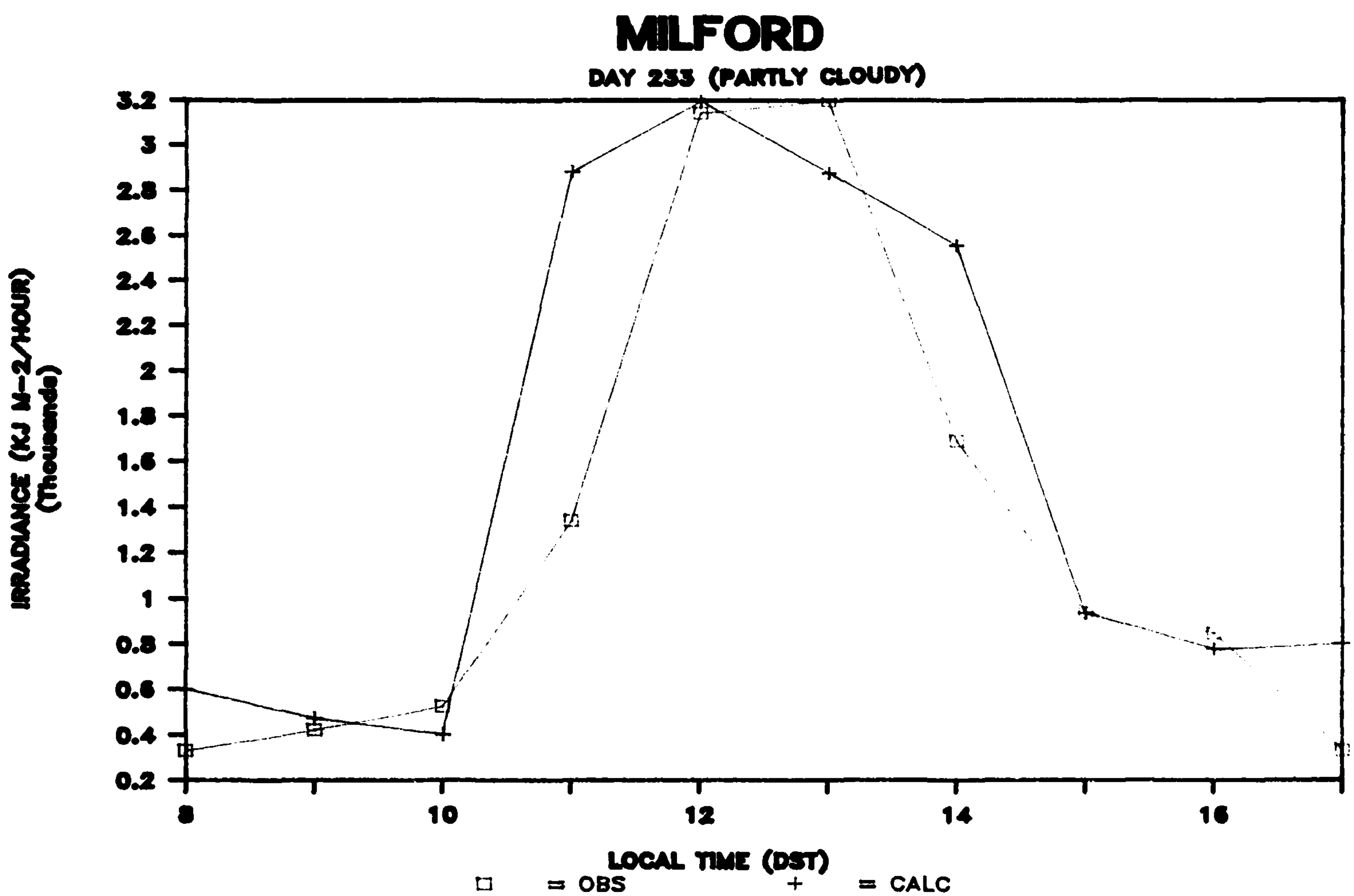


Fig. 31. Calculated and observed irradiance using the original regression coefficients from the Tarpley (1979) model.

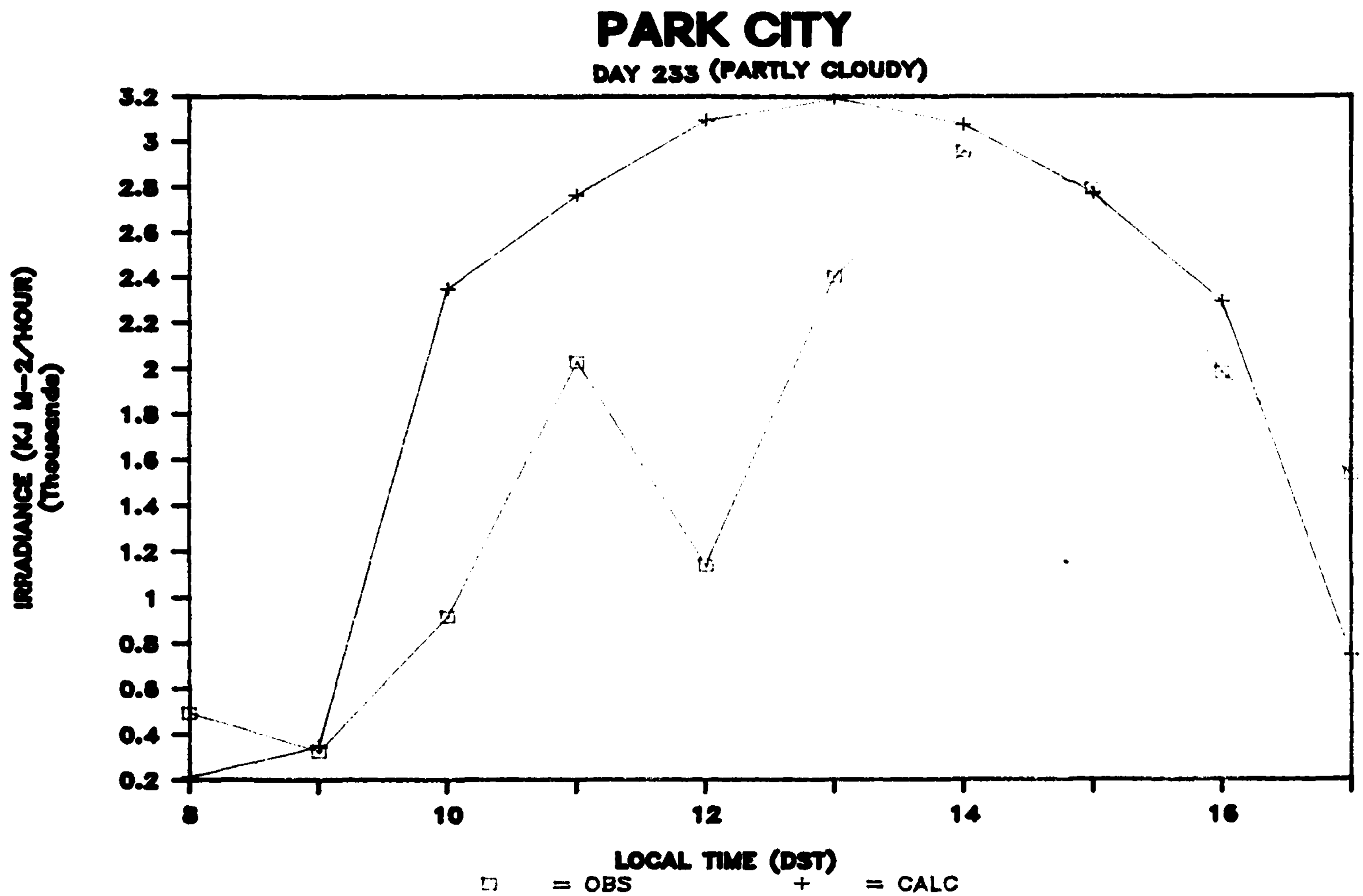


Fig. 32. Calculated and observed irradiance using the original regression coefficients from the Tarpley (1979) model.

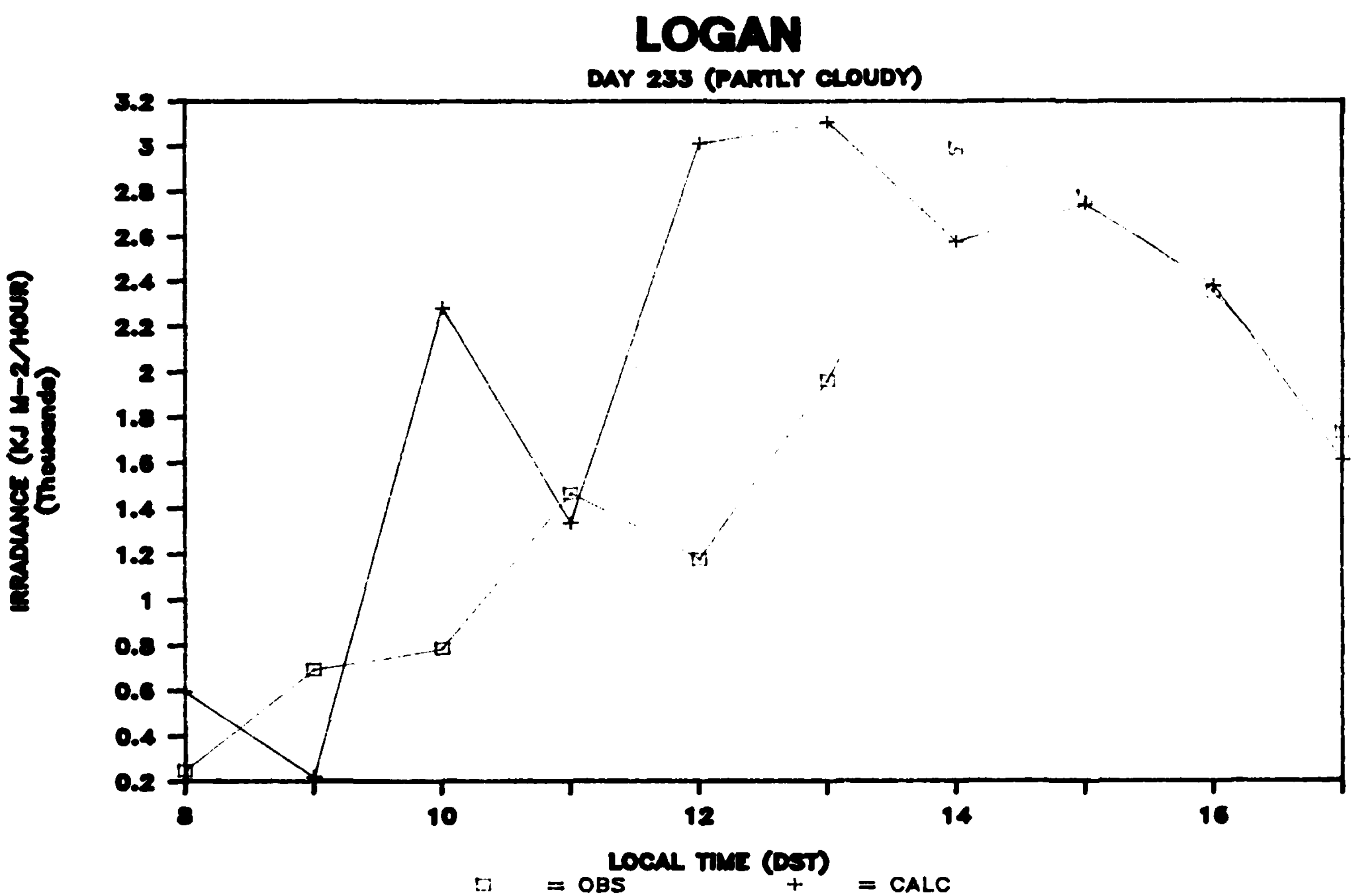


Fig. 33. Calculated and observed irradiance using the original regression coefficients from the Tarpley (1979) model.

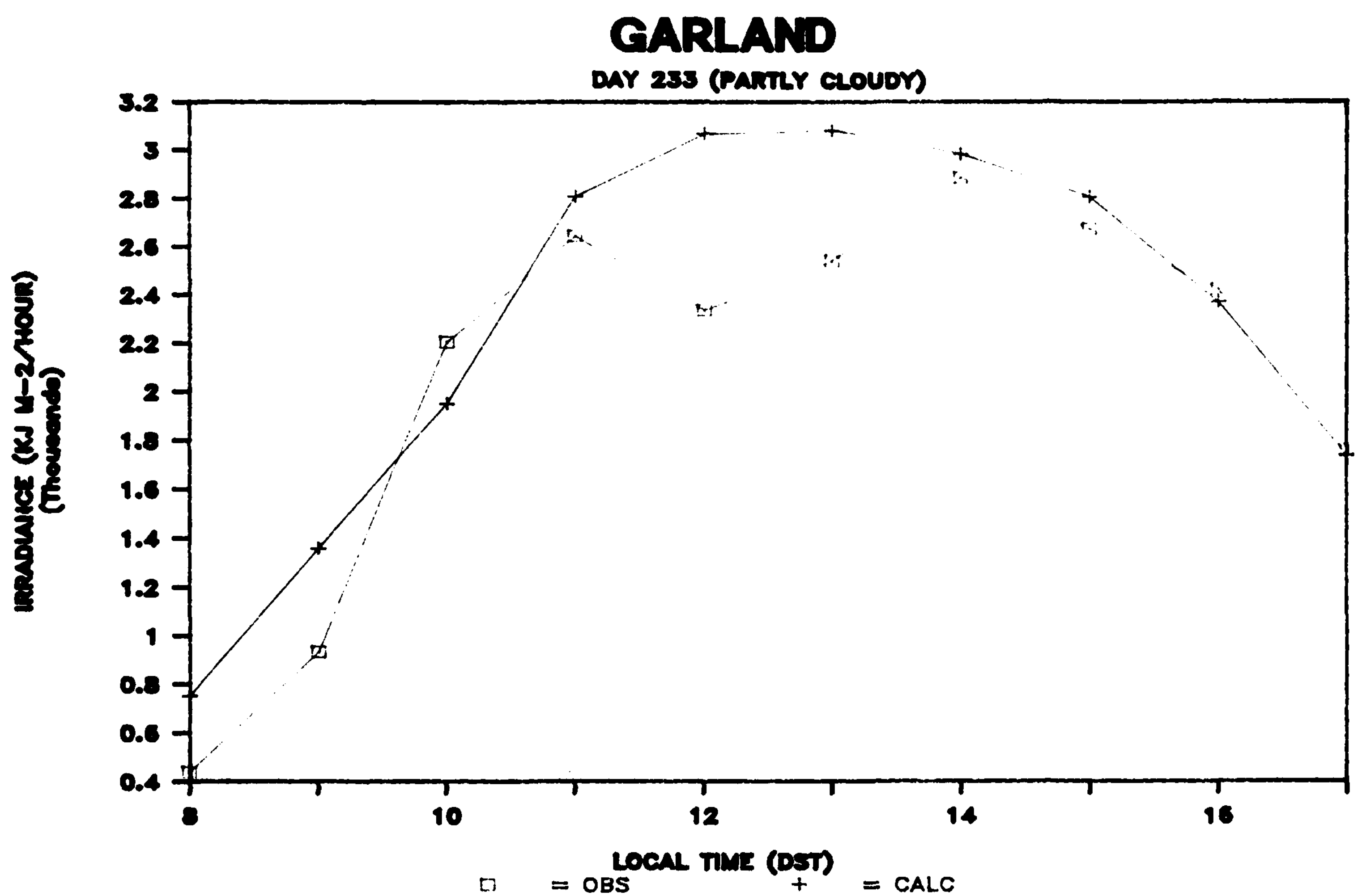


Fig. 34. Calculated and observed irradiance using the original regression coefficients from the Tarpley (1979) model.

Figures 24-27 depict the trend of the model for a clear day. About sixty percent of the sites show curves similar to Figure 24. The figure indicates the model tends to underestimate the irradiance during the morning and mid day hours while the model tends to overestimate the afternoon and evening hours. This trend would produce an overestimation of the daily irradiance value.

For a partly cloudy day, Figures 28-34 indicate that the model generally follows the observed trend line but usually overestimates the early morning and mid day conditions and often misses major events of sunshine or cloudiness. Again, it must be remembered that the irradiance calculation is based on one satellite image per hour. This may not represent the actual condition observed at the site.

The accuracy of the original model was determined by running a statistical analysis of data listed in Table 7. The totaled value listed at the bottom of the table indicates the model's performance under all sky cover conditions. Limitations in the Tarpley (1979) model become apparent when it is used to calculate cloudy conditions. Although the performance of the model is quite good for clear days, an attempt is made to improve the model's overall performance by determining new regression coefficients.

a. Regression coefficients

The development of new regression coefficients was accomplished using a subset of the data that represented various conditions (elevation, latitude, longitude, etc.) over the entire network. The analysis centered on days 172, 174 and 233 to represent various sky cover conditions.

The Tarpley (1979) model contains two sets of regression coefficients. The first set of values correspond to the three cloud categories. Since the original model was developed for a similar season, elevation and predominate cloud type the original coefficients are utilized here. The other set of regression coefficients are related to the clear brightness calculation. The clear brightness calculation is accomplished for each hour and used in the final irradiance calculation. Clear brightness (B) is listed as:

$$B = a + b\cos\theta + c\sin\theta\cos\phi + d\sin\theta\cos^2\phi \quad \text{(Tarpley, 1979)}$$

where θ is the local solar zenith angle, ϕ the sun-satellite azimuth angle and (a), (b), (c), and (d) are the regression coefficients of interest.

The new regression coefficients were calculated using an available software package called Number Cruncher. Coefficients would ideally be determined for each study site, although Raphael and Hay (1984) showed the use of locally-derived coefficients did little to improve the

performance of the model. The revised coefficients are: a = 45.32, b = 61.74, c = 12.85, d = 22.12.

b. The revised model results

The revised model was tested over all the sites using all the available data. Statistical comparison is conducted on the same days used in the initial test of the model. The hourly average statistics at select sites are listed in Table 8 (see Appendix for statistics on the individual sites).

From the results in Table 8 and the Appendix, an improvement in the model was observed for partly cloudy sky conditions. As with the Hay and Hanson (1978) model, a slight decrease in performance is seen for cloudy days, a result of the bias of our data toward cloudy days.

Figures 35-38 indicate the performance of the model for a clear day using the revised regression coefficients. The morning and mid day estimates are now very close to the observed irradiance values but the model's performance tends to slightly decrease during the afternoon and evening hours. This suggests that this trend may be due to an increasing solar zenith angle and a high aerosol count that would be be associated with a clear afternoon rather than a clear morning.

Figures 39-45 indicate that the revision of the regression coefficients can effect the shape of the

Table 8. The hourly statistics at select sites using the revised coefficients from the Tarpley (1979) model for clear (day 172), and partly cloudy (days 174 and 233) sky conditions.

	IRRADIANCE					
DAY	OBS	CALC	N	MBE%	RMSE%	LOCATION
172	26049.0	25441.3	11	2.4	7.9	CEDAR CITY
172	25942.9	26552.5	11	-2.3	7.6	ST. GEORGE
172	26494.1	26325.1	11	.6	2.1	GARLAND
172	26305.7	26394.6	11	-.3	1.1	SPRINGVILLE
174	20562.5	19351.4	11	6.3	20.8	CEDAR CITY
174	23403.2	18830.6	11	24.3	80.5	MILFORD
174	23564.4	22393.8	11	5.2	17.3	DELTA
233	12459.4	13078.2	9	-4.7	14.2	MILFORD
233	15059.9	18697.9	9	-19.5	58.4	PARK CITY
233	14469.1	16802.6	9	-13.9	41.7	LOGAN
233	19094.4	19954.4	9	-4.3	12.9	GARLAND
TOT:	233404.6	233822.4	113	-.2		

estimated irradiance value curve, not just the height at which the curve peaks. The calculated line now mirrors the observed irradiance line quite well. The model, however, has a tendency to underestimate the observed irradiance value. Occasionally, the performance of the model also

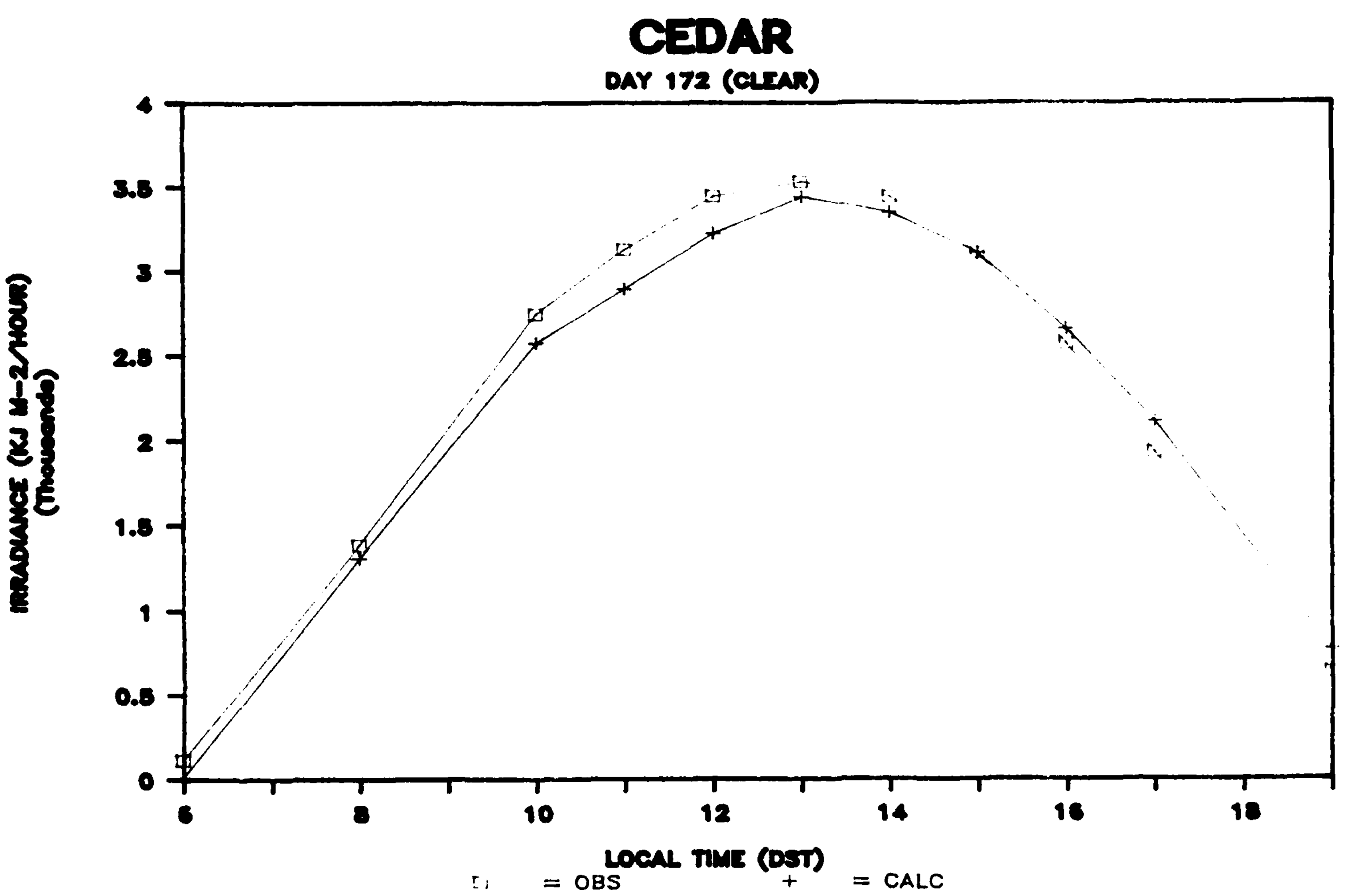


Fig. 35. Calculated and observed irradiance using the improved regression coefficients in the Tarpley (1979) model.

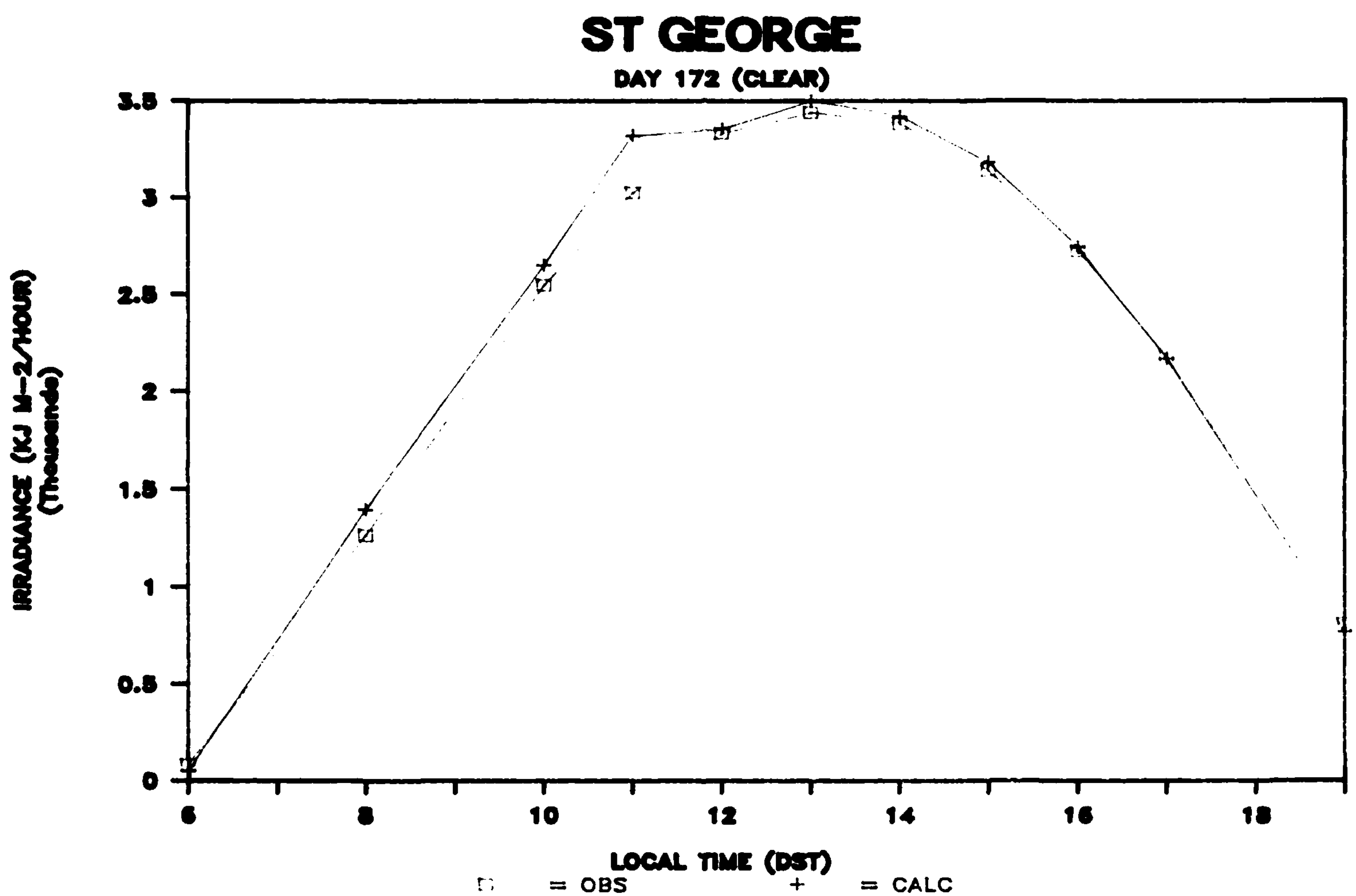
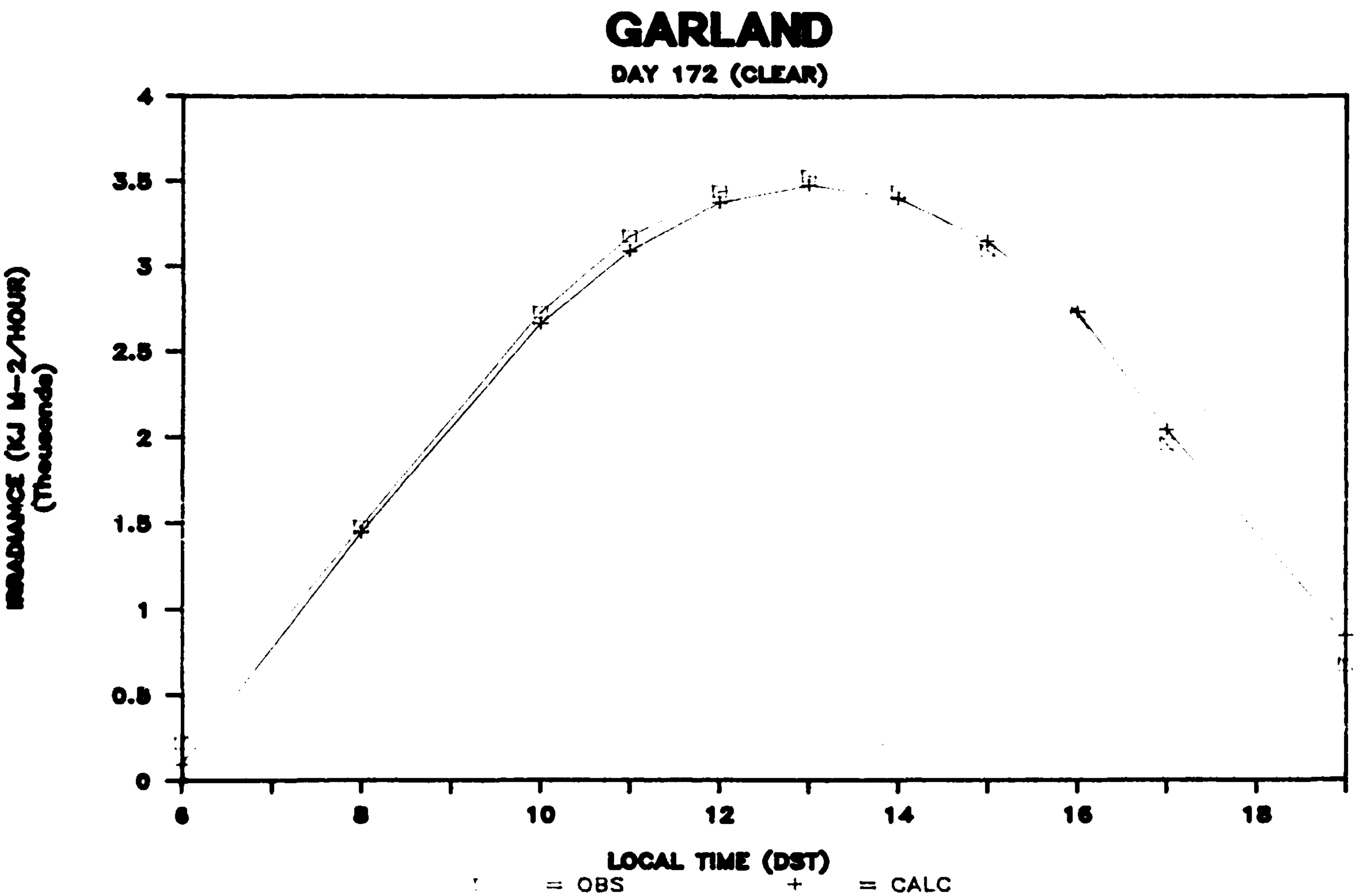
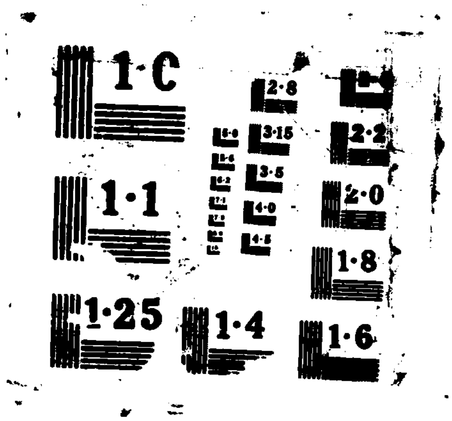


Fig. 36. Calculated and observed irradiance using the improved regression coefficients in the Tarpley (1979) model.



[illegible] and observed irradiance using the improved regression [illegible] the Tarpley (1979) model.

AD-A188 414 ESTIMATING THE SOLAR IRRADIANCE OF AN INTERMOUNTAIN 2/2
REGION USING GOES (GE (U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH M S WALTERS 1987
UNCLASSIFIED AFIT/CI/NR-87-112T F/G 4/2 NL



1·1
1·25
1·4
1·6
1·8
2·0
2·2
2·8
3·15
3·5
4·0
4·5

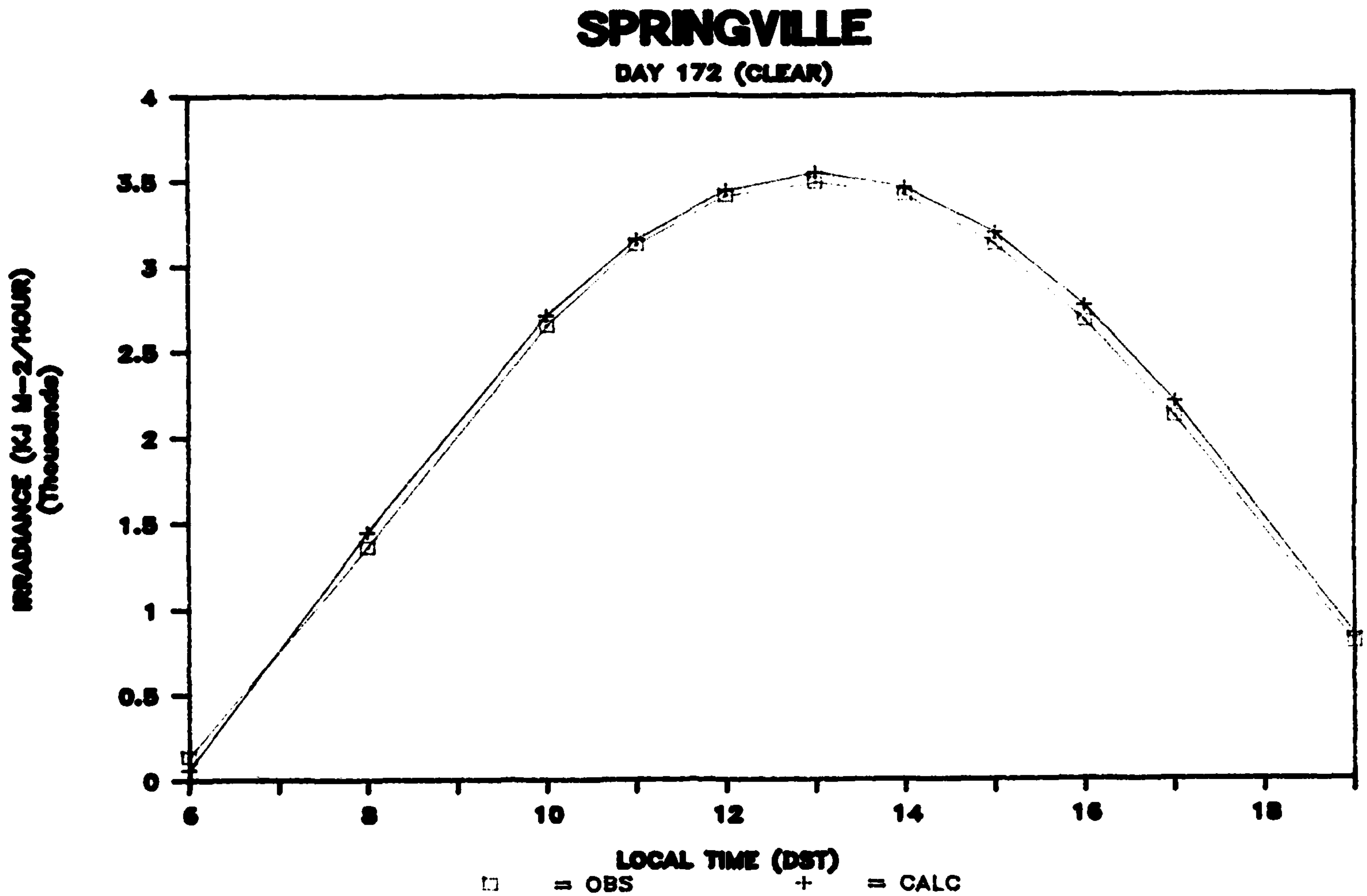


Fig. 38. Calculated and observed irradiance using the improved regression coefficients in the Tarpley (1979) model.

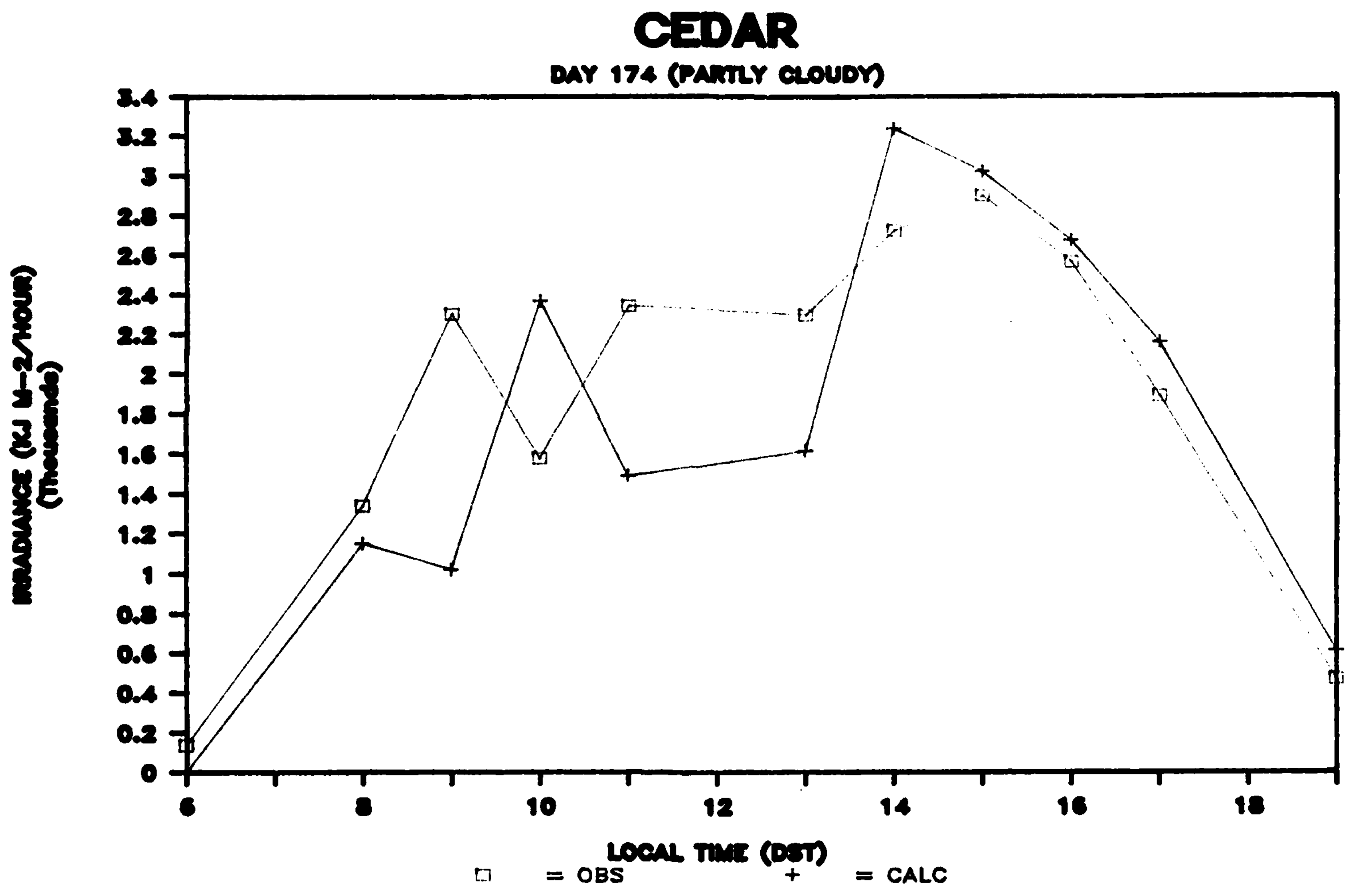


Fig. 39. Calculated and observed irradiance using the improved regression coefficients in the Tarpley (1979) model.

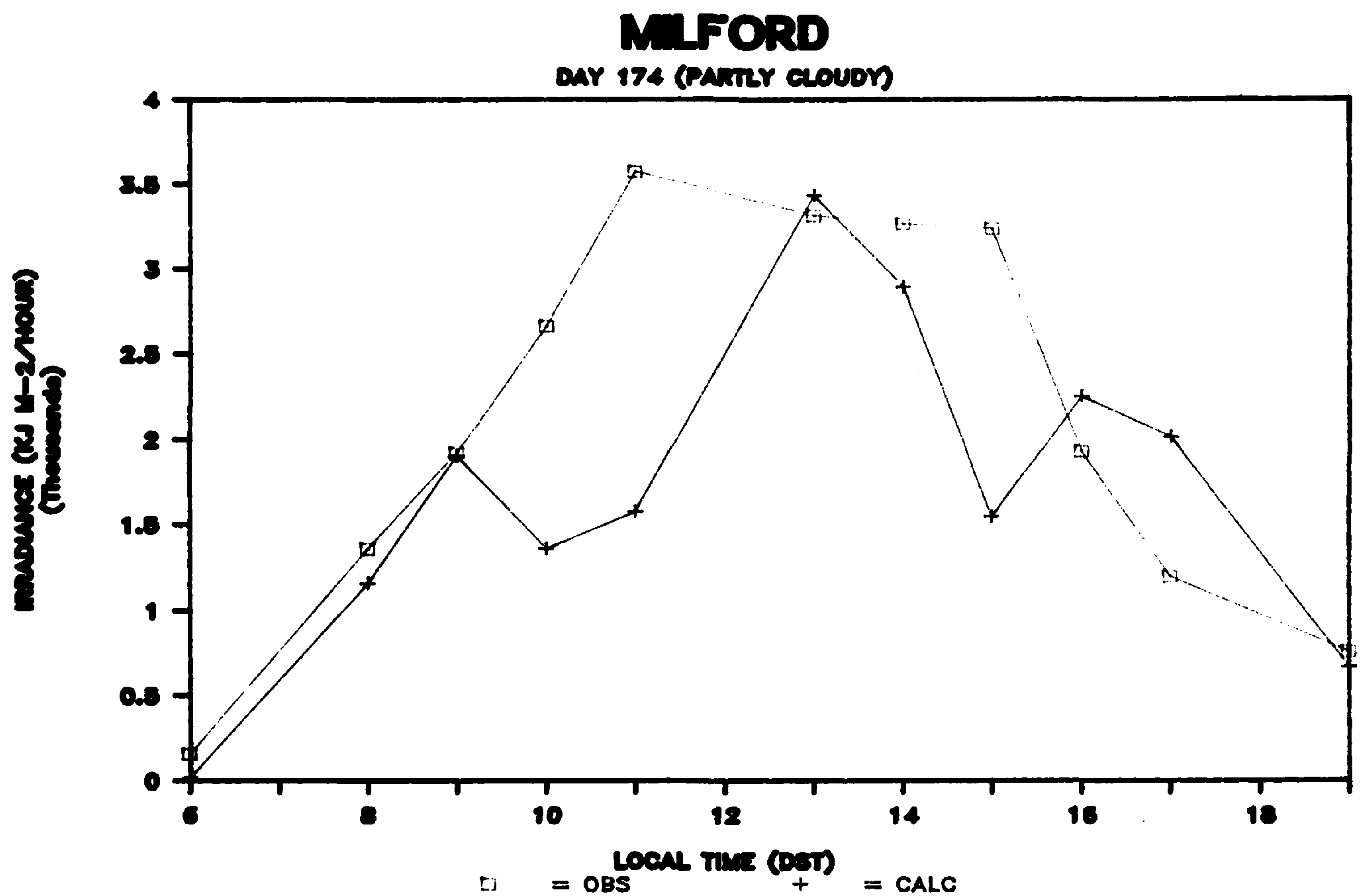


Fig. 40. Calculated and observed irradiance using the improved regression coefficients in the Tarpley (1979) model.

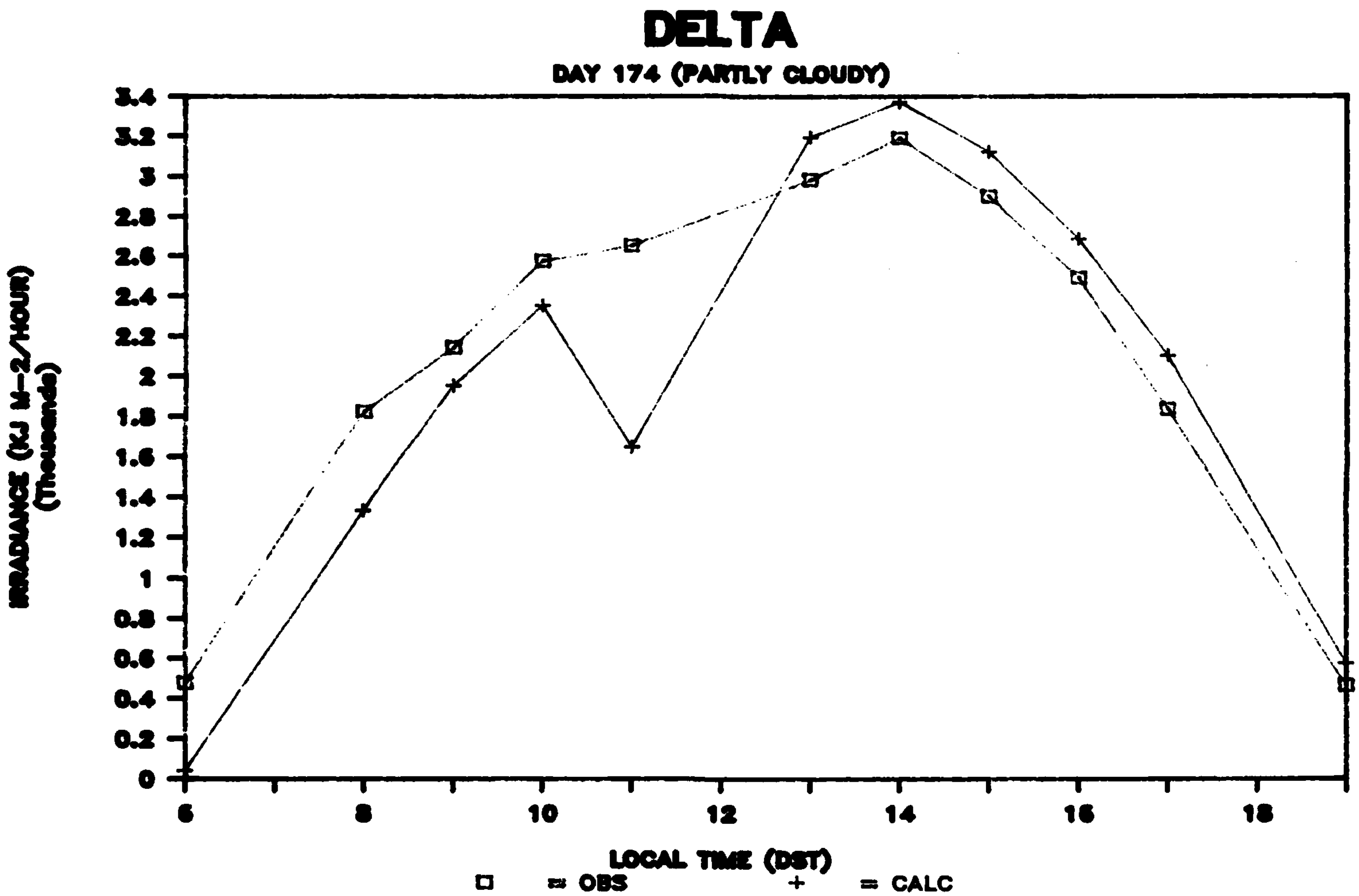


Fig. 41. Calculated and observed irradiance using the improved regression coefficients in the Tarpley (1979) model.

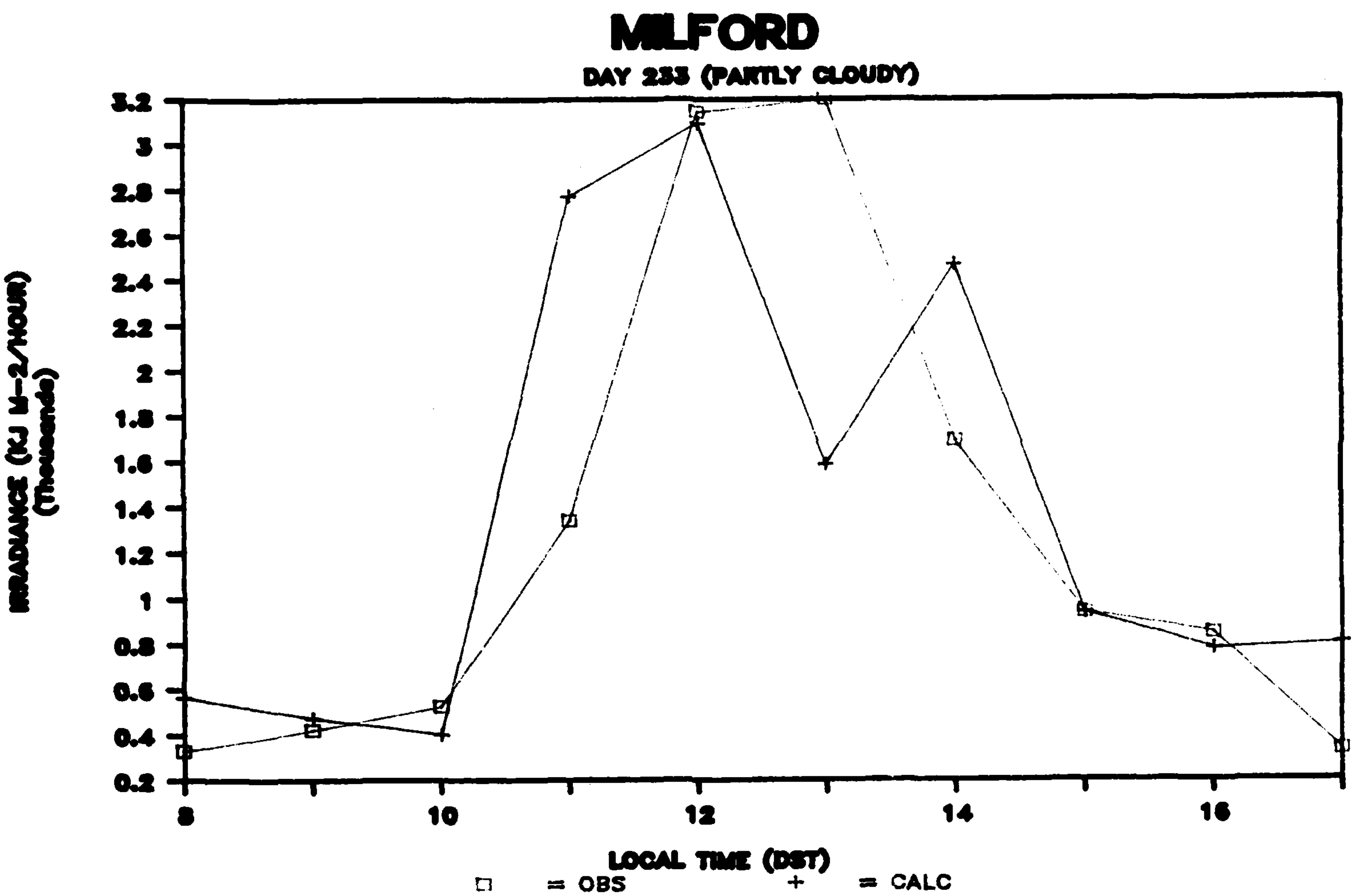


Fig. 42. Calculated and observed irradiance using the improved regression coefficients in the Tarpley (1979) model.

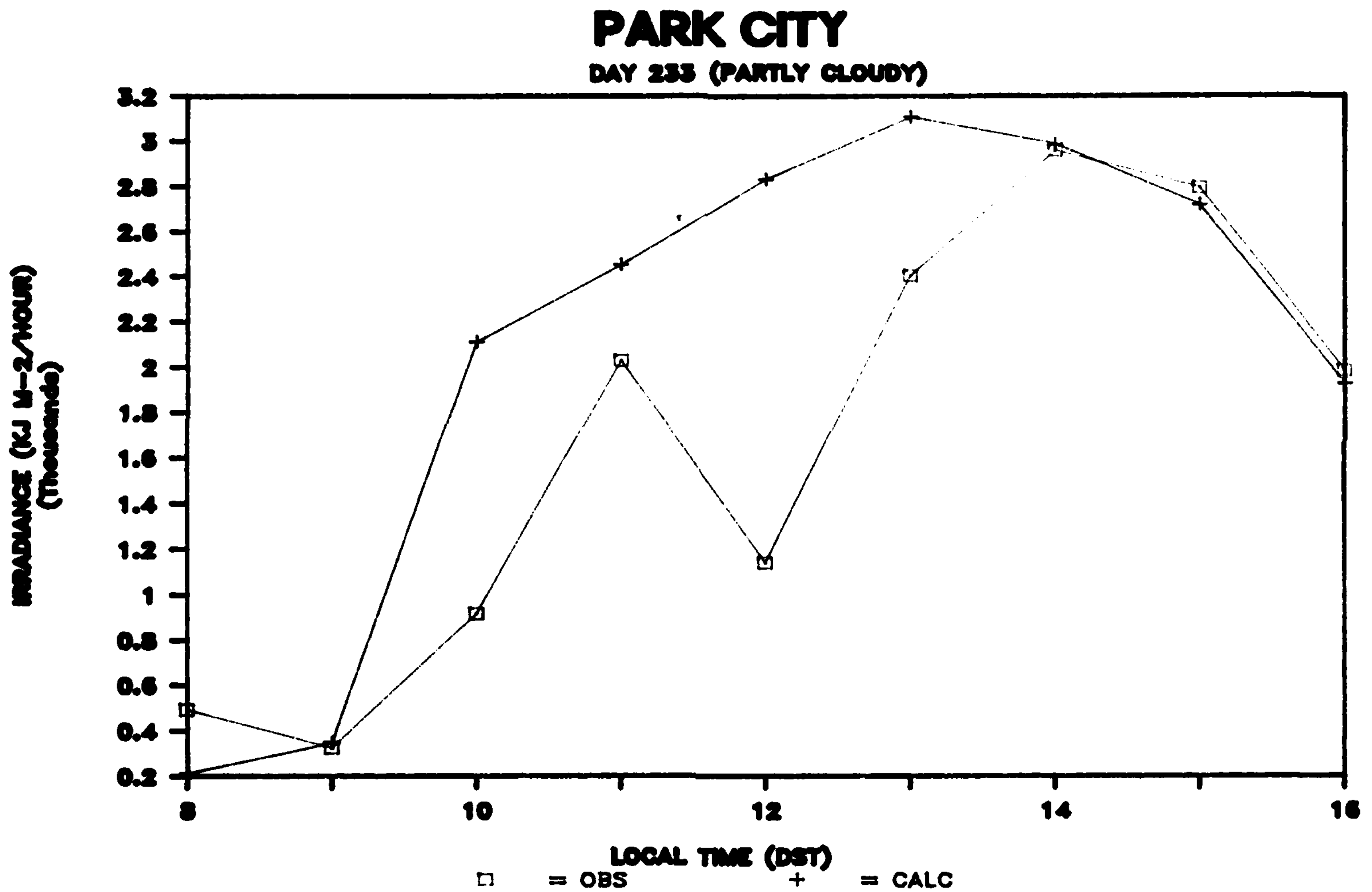


Fig. 43. Calculated and observed irradiance using the improved regression coefficients in the Tarpley (1979) model.

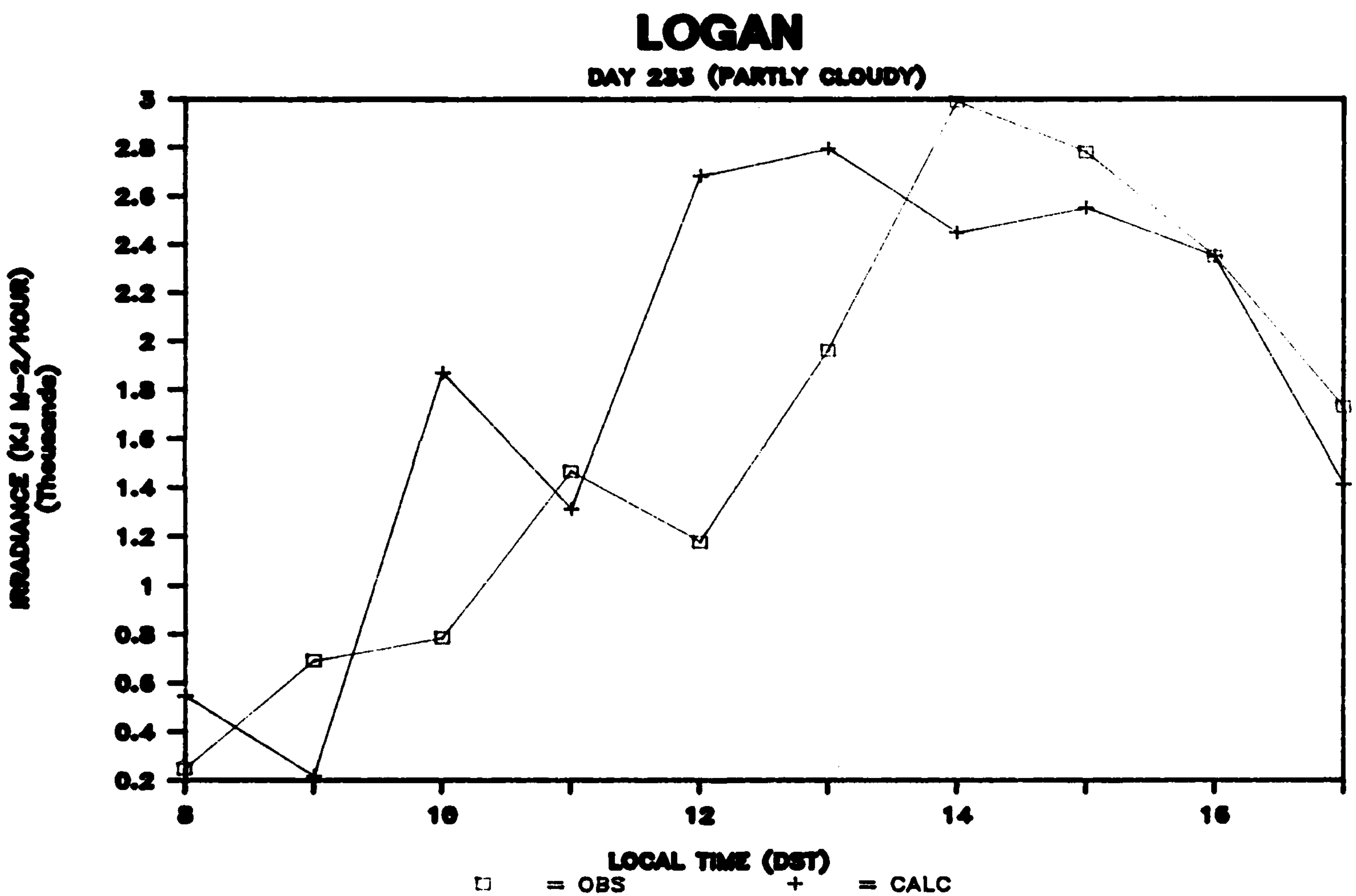


Fig. 44. Calculated and observed irradiance using the improved regression coefficients in the Tarpley (1979) model.

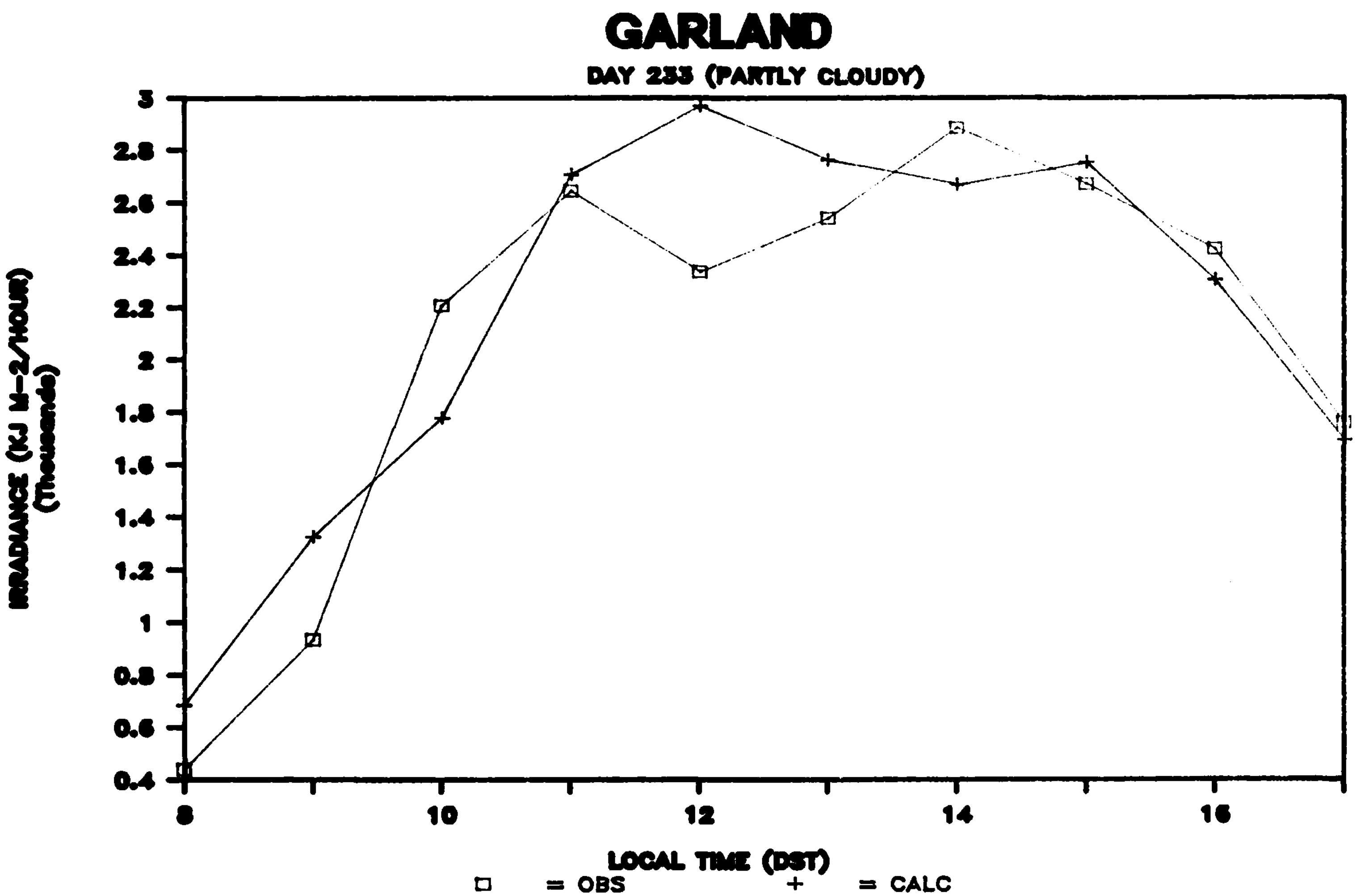


Fig. 45. Calculated and observed irradiance using the improved regression coefficients in the Tarpley (1979) model.

appears to suffer from the inability of only one satellite image to represent the conditions over the entire hour. Additionally, the model continues to have some trouble with a thin overcast day (day 232), as with the Hay and Hanson (1978) model.

3. Summary

The summary statistics for clear, partly cloudy, and overcast sky conditions and the total sample are presented in Table 9 for both of the revised models. Several factors should be noted.

The results from this study indicate that the Hay and Hanson (1978) model performs slightly better than the Tarpley (1979) model for both the total hourly and daily values. Raphael and Hay (1984), reported similar results from their use of the two models over southwest Canada.

The Tarpley (1979) model performed better for a clear day while the Hay and Hanson (1978) model performed better for the partly cloudy situation.

For the Hay and Hanson (1978) model the daily (RMSE% 9.7) and hourly (RMSE% 19.1) statistics for the total sample were similar to those quoted by Hay and Hanson (1978).

For the Tarpley (1979) model, the daily correlation coefficient of .9611 was slightly better than the one quoted by Tarpley (1979). The short term performance

Table 9. Summary statistics showing the performance of the original and revised models for clear, partly cloudy and overcast sky conditions on an hourly (h) and daily (d) basis. Units are KJ m-2/hour.

Condition	N	Time	RMSE	RMSE (%)	Mean Obs	Mean Calc
Revised Hay Model:						
Clear days	294	h	234.2	9.4	2470.2	2438.9
Partly Cloudy days	519	h	421.5	18.3	2221.8	2302.9
Total sample	1183	h	411.7	19.1	2043.4	2159.3
	137	d	1783.5	9.7	17371.0	18302.3
Revised Tarpley Model:						
Clear days	293	h	240.8	9.4	2482.1	2542.4
Partly Cloudy days	508	h	516.6	21.8	2223.3	2367.4
Total sample	1151	h	518.9	23.9	2060.3	2172.7
	137	d	1949.8	10.7	17219.9	18150.8

statistic obtained for the total sample is, however, higher than that reported by Tarpley (1979) for both the hourly and daily analysis.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The intention of this thesis was to determine if a reliable method of estimating solar irradiance could be demonstrated for a mountainous region using satellite data. A comparison has been accomplished using two statistical models, the results showing slightly better performance from one of these models. Some anomalies were expected and found. The development of regression coefficients more suitable to this region improved the performance of both models for most situations. In comparing the results of this study with the work done by the original developer, similar results were obtained.

The results from this study demonstrates slightly better performance by the Hay and Hanson (1978) model over the Tarpley (1979) model in estimating solar irradiance under partly cloudy and overcast skies. The Tarpley (1979) model proved better able to estimate irradiance under a clear sky. Both models systematically overestimate overcast conditions while for partly cloudy conditions, the Hay and Hanson (1978) model generally underestimates and the Tarpley (1979) model overestimates.

Several irregularities were obesrved at the Park City site, the only site that is truly in mountainous terrain.

The effects of high elevation and complex terrain, no doubt cause variability in both models. Sites at higher elevations characteristically receive more insolation than sites at low elevation. The development of new regression coefficients may help to alleviate some of this variability. The simple statistical framework of both models makes their own use over very complex terrain a difficult matter.

As pointed out by the original developers, the models have several shortcomings. Both models inadequately handle cloud absorption. It has been estimated that up to 25% of the incident visible radiation can be absorbed by certain clouds (Tarpley, 1979). It would be necessary to determine cloud type and thickness to account for this factor. Another factor to be considered for inclusion within the models are the effects of aerosols.

For particular use over a high elevation region with geographic variations in albedo - such as Utah, several recommendations are in order. The look-up table calibration technique used in the Hay and Hanson (1978) model needs further study. For the Tarpley (1979) model, the regression coefficients used in determining the three cloud categories may not be totally suitable for this area. The precipitable water values calculated for the study did not take into account the high elevations experienced over the network. The precipitable water values, therefore, may be too large. The results produced from both models depend, to a great

extent, upon accurate navigation. Probably of most benefit to both models would be the employment of a larger data set including data from other seasons.

LITERATURE CITED

Atwater, M. A., and J. T. Ball, 1976: Comparison of radiation computations using observed and estimated precipitable water. J. Appl. Meteorol., 15: 1319-1320.

Bingham, G. E., L. F. Hall, and L. E. Hipps, 1984: Global solar irradiance in Utah, 1981-1984. Research Report 105, Logan, Utah, October 1985.

Brakke, T. W. and E. T. Kanemasu, 1981: Insolation estimation for satellite measurements of reflected radiation. Remote Sensing of Environment, 11: 157-167.

Cano, D., J. M. Monget, M. Albuisson, H. Guillard, N. Regas, and L. Wald, 1986: A method for the determination of the global solar radiation from meteorological satellite data. Solar Energy, 37(1): 31-39.

Clark, D. J., 1983. The GOES user's guide. U.S. Dept. of Commerce, Washington, D.C.

Gautier, C., 1982: Mesoscale insolation variability derived from satellite data. J. Clim. Appl. Meteorol., 21(1): 51-58.

____, 1983: Insolation estimates from satellites, Final Report for NOAA Contract Na81AA-H.00024 Mod. 2, May.

____, G. Diak and S. Masse, 1980: A simply physical model to estimate incident solar radiation at the surface from GOES satellite data. J. Clim. Appl. Meteorol., 19(8): 1005-1012.

____, and K. B. Katsaros, 1984: Insolationduring STREX: 1. Comparisons between surface measurements and satellite estimates. J. Clim. Appl. Meteorol., 89(D7): 11779-11788.

Halpern,P. 1984: Ground level solar energy estimates using GOES measurements and realistic model atmospheres. Rem. Sens. Environ., 15: 47-61.

Hambrick, L. N. and D. R. Phillips, 1980: Earth locating image data of spin-stabilized geosynchronous satellites. NOAA Tech. Memo. NESS 111, 49pp.

Hay, J. E. and K. J. Hanson, 1978: A satellite based methodology for determining solar irradiance at the ocean surface during GATE. Bull. Amer. Meteor. Soc., 59: 1549.

Hiser, H. W. and H. V. Senn, 1980: Mesoscale mapping of available solar energy at the earth's surface by use of satellites. Solar Energy, 24: 129-141.

Justus, C. G., M. V. Paris and J. D. Tarpley, 1986: Satellite-measured insolation in the United States, Mexico and South America. Rem. Sens. Env., 20: 57-83.

Klink, J. C. and K. J. Dellhopf, 1986: An evaluation of satellite-based insolation estimates for Ohio. J. Clim. Appl. Meteorol., 25: 1741-1751.

Moser, W. and E. Raschke, 1984: Incident solar radiation over Europe estimated from METEOSAT data. J. Clim. Appl. Meteorol., 23: 166-170.

Pinker, R. T. and L. A. Cario, 1984: Surface radiation budget from satellites. Mon. Wea. Rev., 112: 209-215.

Powell, G. L., A. J. Brazel and M. J. Pasqualetti, 1984: New approach to estimating solar radiation from satellite imagery. Prof. Geog., 36(2): 227-233.

Raphael, C., 1983: Models for estimating solar irradiance at the earth's surface from satellite data: An initial assessment. Rep. No. 83-1, Canadian Climate Centre, Unpublished Manuscript 332 pp.

Raphael, C. and J. E. Hay, 1984: An assessment of models which use satellite data to estimate solar irradiance at the earth's surface. J. Clim. Appl. Meteorol., 23(5): 832-844.

Sellers, W. D. 1965: Physical Climatology. The University of Chicago Press, 272 pp.

Shenk, W. E. and V. V. Salomonson, 1972: A simulation study exploring the effects of sensor spatial resolution on estimates of cloud cover from satellites. J. Clim. Appl. Meteorol., 11: 214-220.

Smith, W. L., 1966: Note on the relationship between total precipitable water and surface dew point. J. Clim. Appl. Meteorol., 5: 726-727.

Tarpley, J. D., 1979: Estimating incident solar radiation at the surface from geostationary satellite data. J. Appl. Meteorol., 18(9): 1172-1181.

APPENDIX

The following notation applies to the Tables listed in the Appendix.

OBS	=	Observed irradiance summed for the day.
CALC	=	Calculated irradiance summed for the day.
N	=	Number of hours used in the calculation.
MBE	=	Mean bias error
RMSE	=	Root mean square error
MBE%	=	Relative mean bias error
RMSE%	=	Relative root mean square error
R	=	Correlation coefficient
R SQ	=	Coefficient of determination
JD	=	Julian day

Table 10. Averaged hourly statistics for June and August using the original Hay and Hanson (1978) model.

STATION:	CEDER								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
27542.2	27441.2	12	8.4	29.1	.4	1.3	.9759	.9525	156
24994.1	24004.9	10	98.9	312.8	4.1	13.0	.9892	.9785	157
18743.5	20449.5	7	-243.7	644.8	-8.3	22.1	.6193	.3835	158
3782.1	5469.7	5	-337.5	754.7	-30.9	69.0	.8423	.7094	159
21162.3	23785.0	10	-262.3	829.4	-11.0	34.9	.8181	.6693	160
26049.0	25413.6	11	57.8	191.6	2.5	8.3	.9917	.9835	172
28403.9	27113.8	12	107.5	372.4	4.8	16.5	.9955	.9911	173
20562.5	22513.0	11	-177.3	588.1	-8.7	28.7	.9213	.8488	174
15344.3	18393.4	11	-277.2	919.3	-16.6	55.0	.8783	.7715	175
19607.8	21180.7	10	-157.3	497.4	-7.4	23.5	.9499	.9024	176
STATION:	CEDAR								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
7779.6	8245.1	3	-155.2	268.8	-5.6	9.8	.9203	.8470	217
19751.0	21733.4	10	-198.2	626.9	-9.1	28.8	.9244	.8544	218
16297.8	17367.5	7	-152.8	404.3	-6.2	16.3	.8335	.6947	220
16666.2	16224.8	8	55.2	156.1	2.7	7.7	.7823	.6119	222
11429.4	13616.9	8	-273.4	773.4	-16.1	45.4	.8318	.6918	232
11263.4	19623.0	9	-928.8	2786.5	-42.0	127.8	-.1542	.0238	233
11527.9	13986.9	10	-245.9	777.6	-17.6	55.6	.9378	.8794	236
19835.4	18255.6	8	197.5	558.6	8.7	24.5	.9200	.8464	237

Table 11. Averaged hourly statistics for June and August using the original Hay and Hanson (1978) model.

STATION:	DELTA								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
28359.2	26216.3	12	178.6	618.6	8.2	28.3	.9525	.9073	156
21947.2	20049.6	9	210.8	632.5	9.5	28.4	.9555	.9129	157
19873.2	19131.4	7	106.0	280.4	3.9	10.3	.8827	.7792	158
5682.0	5537.7	5	28.9	64.5	2.6	5.8	.7742	.5994	159
16227.8	17141.7	9	-101.5	304.6	-5.3	16.0	.9543	.9107	160
28633.8	25829.1	11	255.0	845.6	10.9	36.0	.9335	.8713	173
23564.4	23446.3	11	10.7	35.7	.5	1.7	.9718	.9444	174
10072.1	12053.6	9	-220.2	660.5	-16.4	49.3	.8730	.7621	175
23674.7	22001.5	10	167.3	529.1	7.6	24.1	.9924	.9849	176
STATION:	DELTA								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
6102.7	6503.9	3	-133.7	231.6	-6.2	10.7	.9783	.9570	217
20487.1	21864.3	10	-137.7	435.5	-6.3	19.9	.9632	.9277	218
15197.4	17031.7	7	-262.0	693.3	-10.8	28.5	.8735	.7630	220
19105.8	20093.4	8	-123.4	349.2	-4.9	13.9	.9153	.8378	222
15817.4	17760.6	10	-194.3	614.5	-10.9	34.6	.8152	.6645	236
19144.2	18998.9	8	18.2	51.4	.8	2.2	.9984	.9969	237

Table 12. Averaged hourly statistics for June and August using the original Hay and Hanson (1978) model.

STATION:	GARLAND								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
26997.2	27942.7	12	-78.8	272.9	-3.4	11.7	.9908	.9816	156
22114.2	21595.1	9	57.7	173.0	2.4	7.2	.9918	.9836	157
21211.8	20772.9	7	62.7	165.9	2.1	5.6	.9850	.9702	158
3518.1	3588.9	5	-14.2	31.6	-2.0	4.4	.8604	.7402	159
11602.7	17446.0	9	-649.3	1947.8	-33.5	100.5	.6564	.4308	160
26494.1	26359.5	11	12.2	40.6	.5	1.7	.9949	.9899	172
27959.2	27622.8	11	30.6	101.5	1.2	4.0	.9959	.9919	174
STATION:	GARLAND								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
8336.4	8314.0	3	7.5	12.9	.3	.5	.9121	.8319	217
23532.1	22783.8	10	74.8	236.6	3.3	10.4	.9977	.9954	218
18202.2	16764.0	7	205.5	543.6	8.6	22.7	.9848	.9698	220
14415.6	13783.6	5	126.4	282.7	4.6	10.3	.6513	.4243	221
21543.6	20530.3	8	126.7	358.3	4.9	14.0	.9963	.9926	222
13082.0	17127.8	8	-505.7	1430.4	-23.6	66.8	.7510	.5639	232
19094.4	19868.6	9	-86.0	258.1	-3.9	11.7	.9477	.8982	233
18637.8	16344.9	10	229.3	725.1	14.0	44.4	.8659	.7497	236
19452.6	18627.1	8	103.2	291.9	4.4	12.5	.9825	.9653	237

Table 13. Averaged hourly statistics for June and August using the original Hay and Hanson (1978) model.

STATION: OBS	MILFORD CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
28588.6	27570.3	12	84.9	294.0	3.7	12.9	.9896	.9792	156
22261.6	21316.5	9	105.0	315.0	4.4	13.3	.9943	.9887	157
21606.6	20582.7	7	146.3	387.0	5.0	13.2	.9744	.9495	158
3126.2	5296.7	5	-434.1	970.6	-41.0	91.6	.8578	.7359	159
27226.8	25741.9	11	135.0	447.7	5.8	19.1	.9957	.9914	172
28270.7	26865.1	11	127.8	423.8	5.2	17.4	.9969	.9938	173
23403.2	22600.1	11	73.0	242.1	3.6	11.8	.9203	.8469	174
13210.7	15631.5	10	-242.1	765.5	-15.5	49.0	.8315	.6913	175
19463.1	21040.3	10	-157.7	498.8	-7.5	23.7	.8287	.6868	176

STATION: OBS	MILFORD CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
3293.4	7435.8	3	-1380.8	2391.6	-55.7	96.5	.7756	.6016	217
16730.8	20419.0	10	-368.8	1166.3	-18.1	57.1	.8612	.7416	218
14392.8	17253.9	7	-408.7	1081.4	-16.6	43.9	.5472	.2994	220
5732.3	9423.7	5	-738.3	1650.8	-39.2	87.6	.5748	.3304	221
19428.6	16867.3	8	320.2	905.6	15.2	42.9	.5658	.3201	222
14731.2	13918.7	8	101.6	287.3	5.8	16.5	.5911	.3494	232
12459.4	14411.3	9	-216.9	650.6	-13.5	40.6	.8595	.7387	233
9579.7	15419.2	10	-584.0	1846.6	-37.9	119.8	.8293	.6877	236
17292.6	18621.1	8	-166.1	469.7	-7.1	20.2	.7411	.5492	237

Table 14. Averaged hourly statistics for June and August using the original Hay and Hanson (1978) model.

STATION:	SPRING								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
25659.4	28369.2	12	-225.8	782.3	-9.6	33.1	.9470	.8969	156
22133.7	21807.5	9	36.2	108.8	1.5	4.5	.9974	.9948	157
21804.6	21112.6	7	98.9	261.6	3.3	8.7	.9870	.9741	158
2885.5	5570.9	5	-537.1	1201.0	-48.2	107.8	.8973	.8051	159
10817.6	14433.6	9	-401.8	1205.3	-25.1	75.2	.8601	.7397	160
26305.7	26283.6	11	2.0	6.6	.1	.3	.9988	.9975	172
28177.6	27432.4	11	67.7	224.7	2.7	9.0	.9992	.9983	173
25809.7	25104.9	11	64.1	212.5	2.8	9.3	.9988	.9977	174
16169.9	18015.4	10	-184.5	583.6	-10.2	32.4	.7536	.5679	175
20454.2	21721.8	10	-126.8	400.8	-5.8	18.5	.9356	.8753	176
STATION:	SPRING								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
6760.2	8112.5	3	-450.8	780.7	-16.7	28.9	.6472	.4189	217
21924.5	23091.5	10	-116.7	369.0	-5.1	16.0	.9357	.8755	218
15027.6	13982.0	7	149.4	395.2	7.5	19.8	.5230	.2735	220
9949.9	8439.5	5	302.1	675.4	17.9	40.0	.6509	.4237	221
16775.4	21056.0	8	-535.1	1513.4	-20.3	57.5	.5629	.3169	222
19479.6	17456.6	8	252.9	715.2	11.6	32.8	.8752	.7660	232
15146.3	18223.9	9	-342.0	1025.9	-16.9	50.7	.9263	.8581	233
11063.7	15616.6	10	-455.3	1439.7	-29.2	92.2	.7616	.5800	236
18519.6	18732.5	8	-26.6	75.3	-1.1	3.2	.9994	.9989	237

Table 15. Averaged hourly statistics for June and August using the original Hay and Hanson (1978) model.

STATION:	STGEORGE								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
27565.2	28079.5	12	-42.9	148.5	-1.8	6.3	.9955	.9910	156
21050.4	21746.2	9	-77.3	231.9	-3.2	9.6	.9970	.9941	157
25942.9	25921.9	11	1.9	6.2	.1	.3	.9979	.9958	172
25285.4	26360.2	11	-97.7	324.1	-4.1	13.5	.9755	.9516	173
20494.1	24180.6	12	-307.2	1064.2	-15.2	52.8	.7975	.6361	174
14332.5	16916.4	10	-258.4	817.1	-15.3	48.3	.8040	.6464	175
23674.5	24618.6	10	-94.4	298.6	-3.8	12.1	.9953	.9907	176
STATION:	STGEORGE								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
7345.2	6747.2	3	199.3	345.3	8.9	15.4	.8671	.7519	217
21555.5	22790.2	10	-123.5	390.4	-5.4	17.1	.9960	.9919	218
15346.2	17348.8	7	-286.1	756.9	-11.5	30.5	.9979	.9959	220
13274.4	11019.1	5	451.1	1008.6	20.5	45.8	-.6574	.4322	221
19131.0	20069.9	8	-117.4	332.0	-4.7	13.2	.9715	.9438	222
9649.2	12496.7	8	-355.9	1006.7	-22.8	64.4	.4095	.1677	232
20447.4	21640.0	9	-132.5	397.5	-5.5	16.5	.9964	.9927	233
8712.2	15046.6	10	-633.4	2003.1	-42.1	133.1	.8032	.6452	236
17962.8	18808.9	8	-105.8	299.1	-4.5	12.7	.9995	.9989	237

Table 16. Averaged hourly statistics for June and August using the original Hay and Hanson (1978) model.

STATION:	WILLARD								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
27240.4	27506.8	11	-24.2	80.3	-1.0	3.2	.9991	.9982	173
27867.4	28486.3	12	-51.6	178.7	-2.2	7.5	.9963	.9926	174
21126.8	20843.2	10	28.4	89.7	1.4	4.3	.9256	.8568	175
21361.6	21029.3	10	33.2	105.1	1.6	5.0	.8116	.6587	176
STATION:	WILLARD								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
8008.8	8623.5	3	-204.9	354.9	-7.1	12.3	.9920	.9841	217
22849.0	23448.9	10	-60.0	189.7	-2.6	8.1	.9981	.9963	218
13853.5	15694.5	7	-263.0	695.8	-11.7	31.0	.9409	.8852	220
14433.6	14109.2	5	64.9	145.1	2.3	5.1	.6163	.3798	221
20860.8	21159.6	8	-37.3	105.6	-1.4	4.0	.9996	.9992	222
19264.2	19606.6	9	-38.0	114.1	-1.7	5.2	.9620	.9254	233
9676.3	13595.4	10	-391.9	1239.3	-28.8	91.2	.8166	.6668	236
18382.8	19058.9	8	-84.5	239.0	-3.5	10.0	.9982	.9965	237

Table 17. Averaged hourly statistics for August using the original Hay and Hanson (1978) model.

STATION: OBS	SANTA CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
7944.6	7897.0	3	15.9	27.5	.6	1.0	.9906	.9812	217
22719.0	23304.8	10	-58.6	185.3	-2.5	7.9	.9934	.9868	218
13638.6	14802.5	7	-166.3	439.9	-7.9	20.8	.7930	.6288	220
5968.2	6998.6	5	-206.1	460.8	-14.7	32.9	.8797	.7739	221
21928.8	18979.9	8	368.6	1042.6	15.5	43.9	.7077	.5008	222
17642.4	17430.0	8	26.6	75.1	1.2	3.4	.8100	.6561	232
14659.8	17714.9	9	-339.5	1018.4	-17.2	51.7	.9886	.9774	233
12952.2	15498.3	10	-254.6	805.1	-16.4	52.0	.5306	.2816	236
17643.6	19347.1	8	-212.9	602.3	-8.8	24.9	.9059	.8207	237

Table 18. Averaged hourly statistics for August using the original Hay and Hanson (1978) model.

STATION: OBS	PARKCITY CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
8479.2	7760.4	3	239.6	415.0	9.3	16.0	-.8404	.7062	217
19823.4	24028.9	10	-420.6	1329.9	-17.5	55.3	.7108	.5052	218
13510.8	15917.7	7	-343.8	909.7	-15.1	40.0	.2998	.0899	220
12996.6	12668.1	5	65.7	146.9	2.6	5.8	.2145	.0460	221
17806.8	20091.4	8	-285.6	807.7	-11.4	32.2	.6671	.4451	222
15059.9	19179.8	9	-457.8	1373.3	-21.5	64.4	.7911	.6259	233
8693.8	14310.6	10	-561.7	1776.2	-39.2	124.1	.8252	.6810	237

Table 19. Averaged hourly statistics for August using the original Hay and Hanson (1978) model.

STATION: LOGAN

OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
8363.4	8274.0	3	29.8	51.6	1.1	1.9	.5226	.2731	217
21403.5	23536.9	10	-213.3	674.6	-9.1	28.7	.7670	.5884	218
17897.4	16877.9	7	145.6	385.3	6.0	16.0	.9694	.9397	220
21814.8	21138.3	8	84.6	239.2	3.2	9.1	.9987	.9974	222
12729.0	14029.0	8	-162.5	459.6	-9.3	26.2	.0151	.0002	232
14469.1	17458.3	9	-332.1	996.4	-17.1	51.4	.7235	.5234	233
12095.6	16000.8	10	-390.5	1234.9	-24.4	77.2	.8816	.7772	236
18985.8	19011.5	8	-3.2	9.0	-.1	.4	.9984	.9968	237

Table 20. Averaged hourly statistics for June and August using the revised Hay and Hanson (1978) model.

OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
STATION:	CEDER								
27542.2	26345.2	12	83.1	287.8	3.8	13.0	.9756	.9518	156
18708.5	17528.5	8	147.5	417.2	6.7	19.0	.9903	.9807	157
18743.5	19764.3	7	-145.8	385.8	-5.2	13.7	.6140	.3771	158
3782.1	5206.4	5	-284.9	637.0	-27.4	61.2	.8629	.7446	159
21162.3	22935.6	10	-177.3	560.8	-7.7	24.5	.8154	.6649	160
26049.0	24550.3	11	136.2	451.9	6.1	20.2	.9913	.9826	172
27874.1	25460.2	11	219.4	727.8	9.5	31.4	.9943	.9886	173
21890.3	23668.7	12	-148.2	513.4	-7.5	26.0	.8989	.8079	174
13513.7	15262.1	10	-174.8	552.9	-11.5	36.2	.8686	.7545	175
19607.8	20207.2	10	-59.9	189.5	-3.0	9.4	.9556	.9132	176
STATION:	CEDAR								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
7779.6	7954.1	3	-58.2	100.7	-2.2	3.8	.9061	.8210	217
19751.0	20887.1	10	-113.6	359.3	-5.4	17.2	.9295	.8640	218
16297.8	16748.5	7	-64.4	170.3	-2.7	7.1	.8281	.6858	220
16666.2	15309.8	8	169.5	479.6	8.9	25.1	.7660	.5868	222
11429.4	12683.5	8	-156.8	443.4	-9.9	28.0	.8098	.6558	232
11263.4	18772.5	9	-834.4	2503.1	-40.0	120.0	-.1770	.0313	233
11527.9	12786.4	10	-125.9	398.0	-9.8	31.1	.9399	.8834	236
19835.4	17579.0	8	282.0	797.8	12.8	36.3	.9066	.8219	237

Table 21. Averaged hourly statistics for June and August using the revised Hay and Hanson (1978) model.

STATION:	DELTA								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
28359.2	25256.9	12	258.5	895.5	12.3	42.5	.9515	.9053	156
21947.2	19308.3	9	293.2	879.6	13.7	41.0	.9542	.9106	157
19873.2	18400.3	7	210.4	556.7	8.0	21.2	.8919	.7955	158
5682.0	5284.9	5	79.4	177.6	7.5	16.8	.7576	.5739	159
16227.8	16243.2	9	-1.7	5.1	-.1	.3	.9528	.9079	160
28633.8	24897.5	11	339.7	1126.5	15.0	49.8	.9304	.8656	173
26418.6	25060.6	12	113.2	392.0	5.4	18.8	.9679	.9368	174
10072.1	11090.6	9	-113.2	339.5	-9.2	27.5	.8730	.7622	175
23674.7	21067.5	10	260.7	824.5	12.4	39.1	.9928	.9856	176
STATION:	DELTA								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
6102.7	6145.5	3	-14.2	24.7	-.7	1.2	.9780	.9566	217
20487.1	21039.1	10	-55.2	174.6	-2.6	8.3	.9664	.9339	218
15197.4	16410.7	7	-173.3	458.6	-7.4	19.6	.8717	.7599	220
19105.8	19357.8	8	-31.5	89.1	-1.3	3.7	.9127	.8330	222
15817.4	16741.9	10	-92.4	292.3	-5.5	17.5	.8002	.6403	236
19144.2	18372.4	8	96.5	272.9	4.2	11.9	.9981	.9961	237

Table 22. Averaged hourly statistics for June and August using the revised Hay and Hanson (1978) model.

STATION:	GARLAND								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
26997.2	27064.2	12	-5.6	19.3	-.2	.9	.9908	.9816	156
22114.2	20926.2	9	132.0	396.0	5.7	17.0	.9913	.9826	157
21211.8	20126.7	7	155.0	410.1	5.4	14.3	.9838	.9679	158
3518.1	3325.9	5	38.4	86.0	5.8	12.9	.8656	.7492	159
11602.7	16568.0	9	-551.7	1655.1	-30.0	89.9	.6430	.4135	160
26494.1	25545.0	11	86.3	286.2	3.7	12.3	.9948	.9896	172
27959.2	26776.3	11	107.5	356.7	4.4	14.7	.9957	.9913	174
STATION:	GARLAND								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
8334.4	8041.6	3	98.3	170.2	3.7	6.3	.9102	.8284	217
23532.1	22026.1	10	150.6	476.2	6.8	21.6	.9976	.9952	218
18202.2	16150.5	7	293.1	775.5	12.7	33.6	.9828	.9659	220
14415.6	13305.1	5	222.1	496.6	8.3	18.7	.5924	.3509	221
21543.6	19837.4	8	213.3	603.2	8.6	24.3	.9957	.9914	222
13082.0	16387.4	8	-413.2	1168.6	-20.2	57.0	.7526	.5664	232
19094.4	19078.8	9	1.7	5.2	.1	.2	.9472	.8972	233
18637.8	15299.7	10	333.8	1055.6	21.8	69.0	.8687	.7547	236
19452.6	18012.6	8	180.0	509.1	8.0	22.6	.9814	.9632	237

Table 23. Averaged hourly statistics for June and August using the revised Hay and Hanson (1978) model.

STATION:	MILFORD								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
28588.6	26683.5	12	158.8	550.0	7.1	24.7	.9892	.9786	156
22261.6	20626.4	9	181.7	545.1	7.9	23.8	.9939	.9879	157
21606.6	19906.5	7	242.9	642.6	8.5	22.6	.9716	.9440	158
3126.2	5023.2	5	-379.4	848.4	-37.8	84.4	.8750	.7657	159
27226.8	24893.2	11	212.1	703.6	9.4	31.1	.9953	.9906	172
28270.7	25974.1	11	208.8	692.4	8.8	29.3	.9966	.9932	173
25847.0	24559.1	12	107.3	371.8	5.2	18.2	.8998	.8096	174
13210.7	14622.7	10	-141.2	446.5	-9.7	30.5	.8124	.6600	175
19463.1	20062.5	10	-59.9	189.5	-3.0	9.4	.8305	.6897	176
STATION:	MILFORD								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
3293.4	7112.8	3	-1273.1	2205.1	-53.7	93.0	.7525	.5663	217
16730.8	19522.8	10	-279.2	882.9	-14.3	45.2	.8716	.7596	218
14392.8	16634.5	7	-320.2	847.3	-13.5	35.7	.5452	.2973	220
5732.3	8735.7	5	-600.7	1343.2	-34.4	76.9	.5687	.3234	221
19428.6	15985.3	8	430.4	1217.4	21.5	60.9	.5296	.2805	222
14731.2	13004.5	8	215.8	610.5	13.3	37.6	.5474	.2997	232
12459.4	13347.9	9	-98.7	296.1	-6.7	20.0	.8540	.7294	233
9579.7	14287.4	10	-470.8	1488.7	-33.0	104.2	.8386	.7033	236
17292.6	17966.8	8	-84.3	238.4	-3.8	10.6	.7361	.5419	237

Table 24. Averaged hourly statistics for June and August using the revised Hay and Hanson (1978) model.

STATION:	SPRING								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
25659.4	27502.8	12	-153.6	532.2	-6.7	23.2	.9465	.8960	156
22133.7	21142.3	9	110.2	330.5	4.7	14.1	.9973	.9946	157
21804.6	20469.6	7	190.7	504.6	6.5	17.3	.9852	.9706	158
2885.5	5301.7	5	-483.2	1080.6	-45.6	101.9	.8980	.8064	159
10817.6	13422.8	9	-289.5	848.4	-19.4	58.2	.8539	.7292	160
26305.7	25461.2	11	76.8	254.6	3.3	11.0	.9987	.9974	172
28177.6	26571.1	11	146.0	484.4	6.0	20.1	.9991	.9983	173
29269.9	27496.2	12	147.8	512.0	6.5	22.3	.9990	.9979	174
16169.9	17108.3	10	-93.8	296.7	-5.5	17.3	.7458	.5561	175
20454.2	20778.5	10	-32.4	102.5	-1.6	4.9	.9331	.8707	176
STATION:	SPRING								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
6760.2	7824.8	3	-354.9	614.7	-13.6	23.6	.6445	.4153	217
21924.5	22325.0	10	-40.0	126.6	-1.8	5.7	.9364	.8768	218
15027.6	13237.6	7	255.7	676.6	13.5	35.8	.4902	.2403	220
9949.9	7722.7	5	445.4	996.0	28.8	64.5	.6336	.4014	221
16775.4	20368.2	8	-449.1	1270.2	-17.6	49.9	.5576	.3109	222
19479.6	16711.1	8	346.1	978.8	16.6	46.9	.8633	.7453	232
15146.3	17343.3	9	-244.1	732.3	-12.7	38.0	.9237	.8531	233
11063.7	14517.1	10	-345.3	1092.1	-23.8	75.2	.7512	.5643	236
18519.6	18102.9	8	52.1	147.3	2.3	6.5	.9991	.9982	237

Table 25. Averaged hourly statistics for June and August using the revised Hay and Hanson (1978) model.

STATION:	STGEORGE								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
27565.2	27194.2	12	30.9	107.1	1.4	4.7	.9950	.9900	156
21050.4	21072.1	9	-2.4	7.1	-.1	.3	.9967	.9934	157
25942.9	25079.4	11	78.5	260.3	3.4	11.4	.9978	.9955	172
25285.4	25445.0	11	-14.5	48.2	-.6	2.1	.9765	.9536	173
20494.1	23108.9	12	-217.9	754.8	-11.3	39.2	.7844	.6153	174
14332.5	15962.3	10	-163.0	515.4	-10.2	32.3	.7907	.6251	175
23674.5	23788.8	10	-11.4	36.1	-.5	1.5	.9953	.9906	176
STATION:	STGEORGE								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
7345.2	6390.5	3	318.2	551.2	14.9	25.9	.8344	.6961	217
21555.5	21982.7	10	-42.7	135.1	-1.9	6.1	.9960	.9919	218
15346.2	16724.3	7	-196.9	520.9	-8.2	21.8	.9977	.9955	220
13274.4	10389.7	5	576.9	1290.1	27.8	62.1	-.6734	.4535	221
19131.0	19311.4	8	-22.5	63.7	-.9	2.6	.9680	.9370	222
9649.2	11509.0	8	-232.5	657.5	-16.2	45.7	.4070	.1656	232
20447.4	20864.9	9	-46.6	139.9	-2.0	6.0	.9963	.9926	233
8712.2	13882.2	10	-517.0	1634.9	-37.2	117.8	.7958	.6333	236
17962.8	18148.5	8	-23.2	65.6	-1.0	2.9	.9992	.9985	237

Table 26. Averaged hourly statistics for June and August using the revised Hay and Hanson (1978) model.

STATION:	WILLARD								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
27240.4	26654.1	11	53.3	176.8	2.2	7.3	.9990	.9979	173
24496.6	24461.2	11	3.2	10.6	.1	.5	.9960	.9920	174
21126.8	20057.3	10	107.0	338.2	5.3	16.9	.9191	.8447	175
21361.6	20062.3	10	129.9	410.9	6.5	20.5	.8021	.6433	176
STATION:	WILLARD								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
8008.8	8362.9	3	-118.0	204.5	-4.2	7.3	.9921	.9842	217
22849.0	22715.6	10	13.3	42.2	.6	1.9	.9982	.9964	218
13853.5	15033.3	7	-168.5	445.9	-7.8	20.8	.9399	.8834	220
14433.6	13642.2	5	158.3	354.0	5.8	13.0	.5580	.3114	221
20860.8	20490.1	8	46.3	131.1	1.8	5.1	.9995	.9990	222
19264.2	18801.8	9	51.4	154.1	2.5	7.4	.9579	.9176	233
9676.3	12429.7	10	-275.3	870.7	-22.2	70.1	.7935	.6297	236
18382.8	18459.0	8	-9.5	27.0	-.4	1.2	.9979	.9959	237

Table 27. Averaged hourly statistics for August using the revised Hay and Hanson (1978) model.

STATION:	SANTA								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
7944.6	7599.7	3	115.0	199.1	4.5	7.9	.9914	.9829	217
22719.0	22546.0	10	17.3	54.7	.8	2.4	.9927	.9854	218
13638.6	14091.8	7	-64.7	171.3	-3.2	8.5	.7870	.6194	220
5968.2	6219.9	5	-50.3	112.6	-4.0	9.0	.8723	.7608	221
21928.8	18203.1	8	465.7	1317.2	20.5	57.9	.6659	.4434	222
17642.4	16681.9	8	120.1	339.6	5.8	16.3	.7959	.6334	232
14659.8	16811.1	9	-239.0	717.1	-12.8	38.4	.9869	.9740	233
12952.2	14392.0	10	-144.0	455.3	-10.0	31.6	.4899	.2400	236
17643.6	18741.9	8	-137.3	388.3	-5.9	16.6	.9104	.8288	237

Table 28. Averaged hourly statistics for August using the revised Hay and Hanson (1978) model.

STATION: OBS	PARKCITY CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
8479.2	7460.1	3	339.7	588.4	13.7	23.7	-.8594	.7386	217
19823.4	23310.4	10	-348.7	1102.7	-15.0	47.3	.6887	.4743	218
13510.8	15259.4	7	-249.8	660.9	-11.5	30.3	.2798	.0783	220
12996.6	12134.0	5	172.5	385.8	7.1	15.9	.1879	.0353	221
17806.8	19368.4	8	-195.2	552.1	-8.1	22.8	.6636	.4404	222
15059.9	18346.5	9	-365.2	1095.5	-17.9	53.7	.7922	.6275	233
8493.8	13163.5	10	-447.0	1413.4	-34.0	107.4	.8261	.6824	237

Table 29. Averaged hourly statistics for August using the revised Hay and Hanson (1978) model.

STATION:	LOGAN								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
8363.4	7999.9	3	121.2	209.9	4.5	7.9	.5681	.3227	217
21403.5	22811.2	10	-140.8	445.2	-6.2	19.5	.7659	.5865	218
17897.4	16269.3	7	232.6	615.3	10.0	26.5	.9681	.9373	220
21814.8	20471.4	8	167.9	475.0	6.6	18.6	.9989	.9978	222
12729.0	13157.9	8	-53.6	151.6	-3.3	9.2	-.0325	.0011	232
14469.1	16566.9	9	-233.1	699.3	-12.7	38.0	.7184	.5161	233
12095.6	14941.4	10	-284.6	899.9	-19.0	60.2	.8755	.7665	236
18985.8	18413.5	8	71.5	202.3	3.1	8.8	.9986	.9971	237

Table 30. Averaged hourly statistics for June and August using the original Tarpley (1979) model.

STATION:	CEDER								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
27542.2	28971.9	12	-119.1	412.7	-4.9	17.1	.9897	.9794	156
21828.5	22129.7	9	-33.5	100.4	-1.4	4.1	.9978	.9956	157
18743.5	21799.6	7	-436.6	1155.1	-14.0	37.1	.6673	.4452	158
3782.1	4785.9	5	-200.8	448.9	-21.0	46.9	.9358	.8758	159
18492.3	22296.4	9	-422.7	1268.0	-17.1	51.2	.8296	.6883	160
26049.0	26782.4	11	-66.7	221.1	-2.7	9.1	.9964	.9928	172
27874.1	28073.6	11	-18.1	60.1	-.7	2.4	.9985	.9970	173
20562.5	22582.9	11	-183.7	609.2	-8.9	29.7	.8469	.7172	174
12215.7	11309.8	8	113.2	320.3	8.0	22.7	.8455	.7149	175
21512.8	24506.5	12	-249.5	864.2	-12.2	42.3	.9697	.9403	176
STATION:	CEDAR								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
7779.6	8637.2	3	-285.9	495.1	-9.9	17.2	.9614	.9243	217
19734.0	22747.1	9	-334.8	1004.4	-13.2	39.7	.9217	.8495	218
16297.8	18675.1	7	-339.6	898.5	-12.7	33.7	.8851	.7834	220
16666.2	16646.3	8	2.5	7.2	.1	.3	.7944	.6311	222
11263.4	20639.7	9	-1041.8	3125.4	-45.4	136.3	-.0547	.0030	233
11527.9	10914.0	10	61.4	194.1	5.6	17.8	.8974	.8053	236
19835.4	18956.5	8	109.9	310.7	4.6	13.1	.9262	.8579	237

Table 31. Averaged hourly statistics for June and August using the original Tarpley (1979) model.

STATION:	DELTA								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
28359.2	28408.8	12	-4.1	14.3	-.2	.6	.9620	.9255	156
21947.2	21758.6	9	21.0	62.9	.9	2.6	.9656	.9323	157
19873.2	21045.2	7	-167.4	443.0	-5.6	14.7	.8624	.7438	158
5682.0	5163.1	5	103.8	232.1	10.1	22.5	.6691	.4477	159
16227.8	18456.3	9	-247.6	742.8	-12.1	36.2	.9416	.8865	160
28633.8	27629.1	11	91.3	302.9	3.6	12.1	.9556	.9131	173
23564.4	24777.9	11	-110.3	365.9	-4.9	16.2	.9740	.9488	174
7832.9	6909.1	7	132.0	349.2	13.4	35.4	.8209	.6738	175
25378.7	26321.0	12	-78.5	272.0	-3.6	12.4	.9508	.9040	176
STATION:	DELTA								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
6102.7	5586.9	3	171.9	297.8	9.2	16.0	.8015	.6424	217
20461.2	22492.2	9	-225.7	677.0	-9.0	27.1	.9494	.9015	218
15197.4	18170.9	7	-424.8	1123.9	-16.4	43.3	.8719	.7602	220
19105.8	21893.5	8	-348.5	985.6	-12.7	36.0	.9071	.8229	222
15817.4	14315.6	10	150.2	474.9	10.5	33.2	.5897	.3477	236
19144.2	19832.1	8	-86.0	243.2	-3.5	9.8	.9995	.9989	237

Table 32. Averaged hourly statistics for June and August using the original Tarpley (1979) model.

STATION:	GARLAND								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
26997.2	28286.5	12	-107.4	372.2	-4.6	15.8	.9931	.9863	156
22114.2	21974.0	9	15.6	46.7	.6	1.9	.9966	.9932	157
21211.8	21530.9	7	-45.6	120.6	-1.5	3.9	.9940	.9880	158
3518.1	3323.1	5	39.0	87.2	5.9	13.1	.8727	.7617	159
11602.7	15966.8	9	-484.9	1454.7	-27.3	82.0	.5077	.2577	160
26494.1	26760.0	11	-24.2	80.2	-1.0	3.3	.9969	.9937	172
27959.2	28096.3	11	-12.5	41.3	-.5	1.6	.9985	.9970	176
STATION:	GARLAND								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
8336.4	8733.4	3	-132.3	229.2	-4.5	7.9	.9321	.8687	217
23464.2	23984.2	9	-57.8	173.3	-2.2	6.5	.9999	.9998	218
18202.2	17902.4	7	42.8	113.3	1.7	4.4	.9839	.9681	220
11508.0	11711.7	4	-50.9	101.9	-1.7	3.5	.9570	.9158	221
21543.6	21768.9	8	-28.2	79.7	-1.0	2.9	.9998	.9997	222
13082.0	17376.1	8	-536.8	1518.2	-24.7	69.9	.7697	.5924	232
19094.4	21182.8	9	-232.0	696.1	-9.9	29.6	.9344	.8731	233
18637.8	12991.9	10	564.6	1785.4	43.5	137.4	.7296	.5323	236
19452.6	19428.2	8	3.0	8.7	.1	.4	.9929	.9858	237

Table 33. Averaged hourly statistics for June and August using the original Tarpley (1979) model.

STATION: MILFORD

OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
28588.6	28978.9	12	-32.5	112.7	-1.3	4.7	.9977	.9955	156
22261.6	22120.9	9	15.6	46.9	.6	1.9	.9981	.9962	157
21606.6	21775.8	7	-24.2	64.0	-.8	2.1	.9936	.9872	158
3126.2	4686.7	5	-312.1	697.9	-33.3	74.5	.9274	.8600	159
27226.8	26844.5	11	34.8	115.3	1.4	4.7	.9990	.9981	172
28270.7	28139.4	11	11.9	39.6	.5	1.5	.9994	.9989	173
23403.2	23598.8	11	-17.8	59.0	-.8	2.7	.9224	.8509	174
12122.6	11987.7	8	16.9	47.7	1.1	3.2	.8433	.7112	175
21443.7	23558.3	12	-176.2	610.4	-9.0	31.1	.9056	.8201	176

STATION: MILFORD

OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
3293.4	7632.5	3	-1446.4	2505.2	-56.9	98.5	.8251	.6807	217
16717.2	21229.4	9	-501.4	1504.1	-21.3	63.8	.8424	.7097	218
14392.8	18591.0	7	-599.7	1586.8	-22.6	59.7	.5892	.3472	220
2831.9	4669.0	4	-459.3	918.5	-39.3	78.7	-.0285	.0008	221
19428.6	17570.5	8	232.3	657.0	10.6	29.9	.5347	.2859	222
14731.2	12792.3	8	242.4	685.5	15.2	42.9	.6361	.4046	232
12459.4	14712.7	9	-250.4	751.1	-15.3	45.9	.8733	.7627	233
9579.7	10763.0	10	-118.3	374.2	-11.0	34.8	.6143	.3773	236
17292.6	19500.1	8	-275.9	780.5	-11.3	32.0	.7968	.6349	237

Table 34. Averaged hourly statistics for June and August using the original Tarpley (1979) model.

STATION: OBS	SPRING CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
25659.4	28628.4	12	-247.4	857.1	-10.4	35.9	.9508	.9040	156
22133.7	22091.6	9	4.7	14.1	.2	.6	.9987	.9973	157
21804.6	21701.9	7	14.7	38.8	.5	1.3	.9984	.9969	158
2885.5	4801.8	5	-383.3	857.0	-39.9	89.2	.9167	.8404	159
10817.6	11682.3	9	-96.1	288.3	-7.4	22.2	.8422	.7093	160
26305.7	26825.3	11	-47.2	156.7	-1.9	6.4	.9994	.9988	172
28177.6	28130.9	11	4.2	14.0	.2	.5	.9992	.9984	173
25809.7	25503.7	11	27.8	92.3	1.2	4.0	.9983	.9966	174
14881.2	13604.2	8	159.6	451.5	9.4	26.6	.6130	.3758	175
21723.2	24074.6	12	-196.0	678.8	-9.8	33.8	.9021	.8138	176

STATION: OBS	SPRING CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
6760.2	8331.6	3	-523.8	907.3	-18.9	32.7	.5957	.3549	217
21900.6	24266.9	9	-262.9	788.8	-9.8	29.3	.8908	.7936	218
15027.6	14039.4	7	141.2	373.5	7.0	18.6	.4393	.1930	220
7038.7	3710.4	4	832.1	1664.1	89.7	179.4	.7580	.5746	221
16775.4	22013.4	8	-654.8	1851.9	-23.8	67.3	.6396	.4090	222
19479.6	16927.3	8	319.0	902.4	15.1	42.6	.7806	.6094	232
15146.3	16924.1	9	-197.5	592.6	-10.5	31.5	.8526	.7269	233
11063.7	12617.6	10	-155.4	491.4	-12.3	38.9	.5470	.2992	236
18519.6	18493.7	8	3.2	9.2	.1	.4	.9588	.9192	237

Table 35. Averaged hourly statistics for June and August using the original Tarpley (1979) model.

STATION:	STGEORGE								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
27565.2	28895.9	12	-110.9	384.1	-4.6	16.0	.9998	.9996	156
21050.4	22331.1	9	-142.3	426.9	-5.7	17.2	.9999	.9998	157
25942.9	26954.6	11	-92.0	305.0	-3.8	12.4	.9988	.9976	172
25285.4	27615.6	11	-211.8	702.6	-8.4	28.0	.9892	.9785	173
18658.7	20623.8	11	-178.7	592.5	-9.5	31.6	.8083	.6533	174
12691.5	12092.6	8	74.9	211.7	5.0	14.0	.9056	.8201	175
26090.0	28881.7	12	-232.6	805.9	-9.7	33.5	.9928	.9856	176
STATION:	STGEORGE								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
7345.2	6986.4	3	119.6	207.2	5.1	8.9	.8330	.6939	217
21547.8	24578.5	9	-336.7	1010.2	-12.3	37.0	.9941	.9883	218
15346.2	18758.7	7	-487.5	1289.8	-18.2	48.1	.9968	.9935	220
10733.4	7188.2	4	886.3	1772.6	49.3	98.6	-.6745	.4550	221
19131.0	21793.9	8	-332.9	941.5	-12.2	34.6	.9476	.8980	222
9649.2	10083.9	8	-54.3	153.7	-4.3	12.2	.4817	.2321	232
20447.4	23310.5	9	-318.1	954.4	-12.3	36.8	.9938	.9877	233
8712.2	12800.6	10	-408.8	1292.9	-31.9	101.0	.7836	.6140	236
17962.8	20138.0	8	-271.9	769.0	-10.8	30.6	.9979	.9958	237

Table 36. Averaged hourly statistics for June and August using the original Tarpley (1979) model.

STATION:	WILLARD								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
27240.4	28016.2	11	-70.5	233.9	-2.8	9.2	.9997	.9994	173
24496.6	25489.5	11	-90.3	299.4	-3.9	12.9	.9963	.9927	174
18592.4	19109.6	8	-64.6	182.8	-2.7	7.7	.8842	.7818	175
23926.3	22599.2	12	110.6	383.1	5.9	20.3	.7010	.4915	176
STATION:	WILLARD								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
8008.8	8810.8	3	-267.3	463.0	-9.1	15.8	.9920	.9840	217
22821.6	24150.2	9	-147.6	442.9	-5.5	16.5	.9985	.9970	218
13853.5	16098.5	7	-320.7	848.5	-13.9	36.9	.9609	.9234	220
11635.8	11919.0	4	-70.8	141.6	-2.4	4.8	.9943	.9886	221
20860.8	21898.0	8	-129.7	366.7	-4.7	13.4	.9980	.9959	222
19264.2	19920.3	9	-72.9	218.7	-3.3	9.9	.9561	.9142	233
9676.3	8266.0	10	141.0	446.0	17.1	54.0	.8454	.7147	236
18382.8	19545.6	8	-145.4	411.1	-5.9	16.8	.9999	.9998	237

Table 37. Averaged hourly statistics for August using the original Tarpley (1979) model.

STATION: OBS	PARKCITY CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
8479.2	6941.7	3	512.5	887.7	22.1	38.4	-.9604	.9223	217
19800.0	22481.0	9	-297.9	893.7	-11.9	35.8	.5913	.3496	218
13510.8	15506.5	7	-285.1	754.3	-12.9	34.1	.1065	.0113	220
10035.0	11514.6	4	-369.9	739.8	-12.8	25.7	.9860	.9722	221
17806.8	20298.5	8	-311.5	880.9	-12.3	34.7	.5723	.3276	222
15059.9	20117.2	9	-561.9	1685.7	-25.1	75.4	.7701	.5930	233
8693.8	10438.4	10	-174.5	551.7	-16.7	52.9	.6663	.4440	237

Table 38. Averaged hourly statistics for August using the original Tarpley (1979) model.

STATION: SANTA

OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
7944.6	7215.1	3	243.2	421.2	10.1	17.5	.9962	.9925	217
22690.8	23539.5	9	-94.3	282.9	-3.6	10.8	.9817	.9637	218
13638.6	14393.2	7	-107.8	285.2	-5.2	13.9	.7919	.6271	220
3047.4	2195.2	4	213.1	426.1	38.8	77.6	.6777	.4593	221
21928.8	18737.8	8	398.9	1128.2	17.0	48.2	.5919	.3503	222
17642.4	17324.6	8	39.7	112.3	1.8	5.2	.7881	.6212	232
14659.8	15429.6	9	-85.5	256.6	-5.0	15.0	.9615	.9244	233
12952.2	11514.5	10	143.8	454.7	12.5	39.5	.4191	.1757	236
17643.6	19398.9	8	-219.4	620.6	-9.0	25.6	.9294	.8638	237

Table 39. Averaged hourly statistics for August using the original Tarpley (1979) model.

STATION: OBS	LOGAN CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
8363.4	8708.5	3	-115.0	199.3	-4.0	6.9	.0727	.0053	217
21378.6	24137.4	9	-306.5	919.6	-11.4	34.3	.6204	.3848	218
17897.4	17237.5	7	94.3	249.4	3.8	10.1	.9656	.9323	220
21814.8	21855.8	8	-5.1	14.5	-.2	.5	.9938	.9876	222
12729.0	13886.7	8	-144.7	409.3	-8.3	23.6	.0476	.0023	232
14469.1	18254.3	9	-420.6	1261.7	-20.7	62.2	.6475	.4193	233
12095.6	9412.2	10	268.3	848.6	28.5	90.2	.8858	.7847	236
18985.8	19504.2	8	-64.8	183.3	-2.7	7.5	.9940	.9881	237

Table 40. Averaged hourly statistics for June and August using the revised Tarpley (1979) model.

STATION:	CEDER								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
27542.2	28012.3	12	-39.2	135.7	-1.7	5.8	.9878	.9757	156
21828.5	21378.5	9	50.0	150.0	2.1	6.3	.9937	.9875	157
18743.5	21046.9	7	-329.1	870.6	-10.9	29.0	.6185	.3825	158
3782.1	4566.9	5	-157.0	351.0	-17.2	38.4	.9337	.8717	159
18492.3	20935.4	9	-271.5	814.4	-11.7	35.0	.7904	.6248	160
26049.0	25441.3	11	55.2	183.2	2.4	7.9	.9938	.9876	172
27874.1	26602.8	11	115.6	383.3	4.8	15.9	.9944	.9889	173
20562.5	19351.4	11	110.1	365.1	6.3	20.8	.8060	.6496	174
12215.7	8864.4	8	418.9	1184.9	37.8	106.9	.8726	.7614	175
21512.8	22087.2	12	-47.9	165.8	-2.6	9.0	.9009	.8117	176
STATION:	CEDAR								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
7779.6	8353.9	3	-191.4	331.6	-6.9	11.9	.9186	.8439	217
19734.0	22060.8	9	-258.5	775.6	-10.5	31.6	.9120	.8317	218
16297.8	17741.1	7	-206.2	545.5	-8.1	21.5	.8240	.6789	220
16666.2	16090.4	8	72.0	203.6	3.6	10.1	.7974	.6359	222
11263.4	19410.7	9	-905.3	2715.8	-42.0	125.9	-.0990	.0098	233
11527.9	9983.4	10	154.5	488.4	15.5	48.9	.9503	.9030	236
19835.4	18423.7	8	176.5	499.1	7.7	21.7	.9221	.8503	237

Table 41. Averaged hourly statistics for June and August using the revised Tarpley (1979) model.

STATION:	DELTA								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
28359.2	26295.8	12	172.0	595.7	7.8	27.2	.9541	.9104	156
21947.2	20166.9	9	197.8	593.4	8.8	26.5	.9533	.9087	157
19873.2	18696.6	7	168.1	444.7	6.3	16.6	.8422	.7093	158
5682.0	5010.9	5	134.2	300.1	13.4	29.9	.6852	.4694	159
16227.8	14528.1	9	188.9	566.6	11.7	35.1	.8615	.7422	160
28633.8	26079.3	11	232.2	770.2	9.8	32.5	.9365	.8770	173
23564.4	22393.8	11	106.4	353.0	5.2	17.3	.9281	.8614	174
7832.9	6934.2	7	128.4	339.7	13.0	34.3	.8180	.6692	175
25378.7	25031.0	12	29.0	100.4	1.4	4.8	.9549	.9118	176
STATION:	DELTA								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
6102.7	5224.8	3	292.6	506.8	16.8	29.1	.8234	.6780	217
20461.2	20806.1	9	-38.3	115.0	-1.7	5.0	.9833	.9669	218
15197.4	17370.7	7	-310.5	821.4	-12.5	33.1	.8664	.7506	220
19105.8	19111.0	8	-.7	1.7	.0	.1	.5882	.3459	222
15817.4	12216.5	10	360.1	1138.7	29.5	93.2	.5978	.3574	236
19144.2	19332.3	8	-23.5	66.5	-1.0	2.8	.9999	.9997	237

Table 42. Averaged hourly statistics for June and August using the revised Tarpley (1979) model.

STATION:	GARLAND								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
26997.2	27720.5	12	-60.3	208.8	-2.6	9.0	.9936	.9872	156
22114.2	21567.3	9	60.8	182.3	2.5	7.6	.9957	.9914	157
21211.8	21280.5	7	-9.8	25.9	-.3	.9	.9933	.9867	158
3518.1	3155.8	5	72.5	162.0	11.5	25.7	.8896	.7915	159
11602.7	13677.3	9	-230.5	691.5	-15.2	45.5	.4255	.1811	160
26494.1	26325.1	11	15.4	50.9	.6	2.1	.9973	.9946	172
27959.2	27696.0	11	23.9	79.4	1.0	3.2	.9983	.9966	176
STATION:	GARLAND								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
8336.4	8539.2	3	-67.6	117.1	-2.4	4.1	.9226	.8513	217
23464.2	23361.4	9	11.4	34.2	.4	1.3	.9996	.9993	218
18202.2	16956.4	7	178.0	470.8	7.3	19.4	.9814	.9631	220
11508.0	9995.6	4	378.1	756.2	15.1	30.3	-.1735	.0301	221
21543.6	21235.5	8	38.5	108.9	1.5	4.1	.9991	.9982	222
13082.0	16345.2	8	-407.9	1153.7	-20.0	56.5	.7450	.5550	232
19094.4	19954.4	9	-95.6	286.7	-4.3	12.9	.9241	.8539	233
18637.8	10319.8	10	831.8	2630.4	80.6	254.9	.8564	.7335	236
19452.6	18996.6	8	57.0	161.2	2.4	6.8	.9904	.9809	237

Table 43. Averaged hourly statistics for June and August using the revised Tarpley (1979) model.

STATION:	MILFORD								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
28588.6	28237.8	12	29.2	101.3	1.2	4.3	.9953	.9907	156
22261.6	21762.6	9	55.4	166.3	2.3	6.9	.9964	.9929	157
21606.6	21264.4	7	48.9	129.3	1.6	4.3	.9839	.9682	158
3126.2	4441.6	5	-263.1	588.2	-29.6	66.2	.9336	.8715	159
27226.8	26269.4	11	87.0	288.7	3.6	12.1	.9968	.9936	172
28270.7	27403.1	11	78.9	261.6	3.2	10.5	.9986	.9972	173
23403.2	18830.6	11	415.7	1378.7	24.3	80.5	.6774	.4588	174
12122.6	8278.4	8	480.5	1359.1	46.4	131.3	.8737	.7633	175
21443.7	22067.3	12	-52.0	180.0	-2.8	9.8	.9081	.8247	176
STATION:	MILFORD								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
3293.4	7447.3	3	-1384.6	2398.3	-55.8	96.6	.7778	.6049	217
16717.2	19686.8	9	-330.0	989.9	-15.1	45.3	.8949	.8009	218
14392.8	17518.0	7	-446.5	1181.2	-17.8	47.2	.5864	.3439	220
2831.9	4669.0	4	-459.3	918.5	-39.3	78.7	-.0285	.0008	221
19428.6	16296.3	8	391.5	1107.4	19.2	54.4	.4183	.1750	222
14731.2	11975.3	8	344.5	974.4	23.0	65.1	.6513	.4242	232
12459.4	13078.2	9	-68.8	206.3	-4.7	14.2	.7188	.5167	233
9579.7	10633.9	10	-105.4	333.4	-9.9	31.4	.6559	.4302	236
17292.6	18838.3	8	-193.2	546.5	-8.2	23.2	.7729	.5974	237

Table 44. Averaged hourly statistics for June and August using the revised Tarpley (1979) model.

STATION:	SPRING								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
25659.4	28057.8	12	-199.9	692.4	-8.5	29.6	.9483	.8993	156
22133.7	21743.8	9	43.3	130.0	1.8	5.4	.9988	.9975	157
21804.6	21379.3	7	60.8	160.7	2.0	5.3	.9926	.9852	158
2885.5	4400.1	5	-302.9	677.4	-34.4	77.0	.9311	.8669	159
10817.6	9400.4	9	157.5	472.4	15.1	45.2	.8641	.7467	160
26305.7	26394.6	11	-8.1	26.8	-.3	1.1	.9994	.9988	172
28177.6	27629.6	11	49.8	165.2	2.0	6.6	.9995	.9990	173
25809.7	24985.2	11	75.0	248.6	3.3	10.9	.9988	.9976	174
14881.2	10214.4	8	583.4	1650.0	45.7	129.2	.6598	.4354	175
21723.2	22366.3	12	-53.6	185.6	-2.9	10.0	.8667	.7512	176
STATION:	SPRING								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
6760.2	8148.8	3	-462.9	801.7	-17.0	29.5	.6325	.4001	217
21900.6	23532.9	9	-181.4	544.1	-6.9	20.8	.9187	.8441	218
15027.6	12807.6	7	317.1	839.1	17.3	45.9	.4990	.2490	220
7038.7	3710.4	4	832.1	1664.1	89.7	179.4	.7580	.5746	221
16775.4	21483.3	8	-588.5	1664.5	-21.9	62.0	.6416	.4117	222
19479.6	16604.4	8	359.4	1016.5	17.3	49.0	.7825	.6124	232
15146.3	15034.5	9	12.4	37.3	.7	2.2	.7445	.5543	233
11063.7	11014.1	10	5.0	15.7	.5	1.4	.6326	.4001	236
18519.6	18212.6	8	38.4	108.5	1.7	4.8	.9630	.9273	237

Table 45. Averaged hourly statistics for June and August using the revised Tarpley (1979) model.

STATION:	STGEORGE								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
27565.2	28397.0	12	-69.3	240.1	-2.9	10.1	.9980	.9960	156
21050.4	21825.2	9	-86.1	258.3	-3.5	10.6	.9994	.9987	157
25942.9	26552.5	11	-55.4	183.8	-2.3	7.6	.9972	.9945	172
25285.4	26181.9	11	-81.5	270.3	-3.4	11.4	.9879	.9759	173
18658.7	17559.1	11	100.0	331.5	6.3	20.8	.7612	.5795	174
12691.5	9467.9	8	403.0	1139.7	34.0	96.3	.9159	.8388	175
26090.0	28166.1	12	-173.0	599.3	-7.4	25.5	.9927	.9855	176
STATION:	STGEORGE								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
7345.2	5629.9	3	571.8	990.4	30.5	52.8	.6843	.4682	217
21547.8	22901.7	9	-150.4	451.3	-5.9	17.7	.9929	.9858	218
15346.2	17353.2	7	-286.7	758.6	-11.6	30.6	.9950	.9900	220
10733.4	6737.4	4	999.0	1998.0	59.3	118.6	-.6976	.4867	221
19131.0	19526.0	8	-49.4	139.6	-2.0	5.7	.9351	.8744	222
9649.2	8336.7	8	164.1	464.0	15.7	44.5	.1750	.0306	232
20447.4	21730.5	9	-142.6	427.7	-5.9	17.7	.9915	.9831	233
8712.2	10299.6	10	-158.7	502.0	-15.4	48.7	.5273	.2780	236
17962.8	19096.2	8	-141.7	400.7	-5.9	16.8	.9987	.9974	237

Table 46. Averaged hourly statistics for June and August using the revised Tarpley (1979) model.

STATION:	WILLARD								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
27240.4	27653.3	11	-37.5	124.5	-1.5	5.0	.9998	.9996	173
24496.6	24959.3	11	-42.1	139.5	-1.9	6.1	.9972	.9945	174
18592.4	17184.1	8	176.0	497.9	8.2	23.2	.7425	.5513	175
23926.3	18494.3	12	452.7	1568.1	29.4	101.7	.6570	.4316	176
STATION:	WILLARD								
OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
8008.8	8714.3	3	-235.2	407.3	-8.1	14.0	.9920	.9840	217
22821.6	23746.0	9	-102.7	308.1	-3.9	11.7	.9990	.9979	218
13853.5	15650.2	7	-256.7	679.1	-11.5	30.4	.9501	.9027	220
11635.8	11170.1	4	116.4	232.9	4.2	8.3	.5386	.2901	221
20860.8	21517.9	8	-82.1	232.3	-3.1	8.6	.9984	.9969	222
19264.2	18856.4	9	45.3	135.9	2.2	6.5	.9586	.9189	233
9676.3	8266.0	10	141.0	446.0	17.1	54.0	.8454	.7147	236
18382.8	19207.3	8	-103.1	291.5	-4.3	12.1	.9999	.9999	237

Table 47. Averaged hourly statistics for

August using the revised Tarpley (1979) model.

STATION: OBS	PARKCITY CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
8479.2	6824.5	3	551.6	955.4	24.2	42.0	-.9529	.9081	217
19800.0	22063.5	9	-251.5	754.5	-10.3	30.8	.6121	.3747	218
13510.8	15116.9	7	-229.4	607.0	-10.6	28.1	.1184	.0140	220
10035.0	10509.3	4	-118.6	237.1	-4.5	9.0	.9455	.8939	221
17806.8	19579.4	8	-221.6	626.7	-9.1	25.6	.6101	.3723	222
15059.9	18697.9	9	-404.2	1212.6	-19.5	58.4	.7971	.6353	233
8693.8	8956.2	10	-26.2	83.0	-2.9	9.3	.7600	.5776	237

Table 48. Averaged hourly statistics for August using the revised Tarpley (1979) model.

STATION: SANTA

OBS	CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
7944.6	7137.0	3	269.2	466.2	11.3	19.6	.9953	.9907	217
22690.8	22824.9	9	-14.9	44.7	-.6	1.8	.9695	.9399	218
13638.6	13394.8	7	34.8	92.1	1.8	4.8	.8481	.7192	220
3047.4	2195.2	4	213.1	426.1	38.8	77.6	.6777	.4593	221
21928.8	17704.3	8	528.1	1493.6	23.9	67.5	.4645	.2157	222
17642.4	16580.1	8	132.8	375.6	6.4	18.1	.7821	.6116	232
14659.8	14408.8	9	27.9	83.7	1.7	5.2	.9449	.8929	233
12952.2	9553.0	10	339.9	1074.9	35.6	112.5	.4405	.1941	236
17643.6	19011.3	8	-171.0	483.6	-7.2	20.3	.9475	.8978	237

Table 49. Averaged hourly statistics for August using the revised Tarpley (1979) model.

STATION: OBS	LOGAN CALC	N	MBE	RMSE	MBE%	RMSE%	R	R SQ	JD
8363.4	8235.9	3	42.5	73.6	1.5	2.7	.6474	.4192	217
21378.6	23776.1	9	-266.4	799.2	-10.1	30.3	.6169	.3805	218
17897.4	16755.7	7	[illegible]	431.5	6.8	18.0	.9636	.9286	220
21814.8	21532.7	8	35.3	99.7	1.3	3.7	.9947	.9895	222
12729.0	11553.3	8	147.0	415.7	10.2	28.8	.0916	.0084	232
14469.1	16781.7	9	-257.0	770.9	-13.8	41.3	.7165	.5134	233
12095.6	9412.2	10	268.3	848.6	28.5	90.2	.8858	.7847	236
18985.8	19203.6	8	-27.2	77.0	-1.1	3.2	.9947	.9894	237

END
DATE
FILMED
3-88
DTIC